Proceedings of the

13th International Conference on Construction in the 21st Century (CITC 13)

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Foreword

The construction industry is being shaped by technology, innovation, leadership, and collaboration, bringing countries and industries closer together. The 13th International Conference on Construction in the 21st Century (CITC-13) is a collaborative effort with HAN University of Applied Sciences in Arnhem, Netherlands. The conference aims to unite professionals in engineering, construction, architecture, and management to foster the exchange of ideas among practitioners, researchers, and educators from around the world.

CITC-13 is a peer-reviewed conference serving as a dynamic platform for sharing knowledge. The implementation of new methods and techniques undergoes thorough scrutiny and rigorous testing, in which CITC-13 plays a vital role. As the construction industry advances in a complex global economy, international collaboration becomes increasingly important for future growth and success.

This May, we are proud to host the thirteenth CITC conference. Previous conferences were held in various locations, including Miami, USA (CITC-I, 2002), Hong Kong, China (CITC-II, 2003), Athens, Greece (CITC-III, 2005), Gold Coast, Australia (CITC-IV, 2007), Istanbul, Turkey (CITC-V, 2009), Kuala Lumpur, Malaysia (CITC-VI, 2011), Bangkok, Thailand (CITC-VII, 2013), Thessaloniki, Greece (CITC-8, 2015), Dubai, UAE (CITC-9, 2017), Colombo, Sri Lanka (CITC-10, 2018), London, United Kingdom (CITC-11, 2019), and Amman, Jordan (CITC-12). All previous conferences were highly successful, thanks to the support of our colleagues worldwide. Now, we proudly present the Thirteenth International Conference on Construction in the 21st Century (CITC-13), a three-day event held at HAN University of Applied Sciences in Arnhem, Netherlands. CITC-13 aims to bring together a diverse community of academics, professionals, government agencies, and students from across the globe to contribute to the industry's future growth.

We sincerely appreciate your presence and hope for your continued support in the future endeavors of CITC.

Thank you and best regards,

Editors:

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Dr. Amelia D. Saul

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Thank you!

CITC-13 Themes

- 3D Printing
- Artificial Intelligence & Machine Learning
- Extended Reality (AR/VR/MR) Systems
- Autonomous Vehicles
- Blockchain systems
- Building Automation
- Building Information Modeling
- Concrete Technology
- Construction 4.0
- Construction Contracts
- Construction Education
- Construction Exoskeletons
- Construction Robotics
- Construction Safety & Health
- Construction Scheduling
- Construction Wearables
- Cost Analysis & Control
- Cultural Issues in Construction
- Design-Build Construction
- Drones in Construction
- Engineering & Construction Materials
- Ethical Issues in Engineering and Construction
- Innovative Systems and Technologies
- Information Technology and Systems
- Infrastructure Systems and Management
- International Construction
- International Construction Issues
- Leadership in Engineering & Construction
- Lean Construction Practices
- Legal Issues in Construction
- Materials and Technology Research
- Modular Construction
- Project and Program Management
- Reality Capture Technologies
- Quality and Productivity Improvement
- Smart City and Society
- Sustainable Design and Construction
- Structural Analysis & Design
- Tall Buildings
- Value Engineering
- Women in Construction

CITC-13 International Scientific Review Committee

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- *Professor Jamal Khatib*
- *Dr. Malik M.A. Khalfan*

Delay and disruption workshop

8th May | Arnhem

For the CITC Conference, Driver Trett provides a workshop on delay and disruption. At the workshop we will explain the principles of planning, delay, and disruption, and how to recognise, analyse and value them.

The planning and associated contractual time-related clauses provide the analyst with the tools to demonstrate the delaying and/or disruptive impact of events occurring during project execution. Driver Trett explains the importance of a well set up programme in relation to the contract for a comprehensive demonstration of delay and/or disruption.

Knowledge

The workshop starts with an explanation of the basic principles of planning in conjunction with time related clauses of the contract, followed by delay and disruption. Subsequently, the participants will be informed about the different methods by which delay, and disruption can be analysed.

Observation and reflection

Each participant has the opportunity to share his/her own experiences regarding planning, delay and disruption in order to make the connection between the theory and their own experiences.

Exploring the theory and actively experiment

The participants are actively guided to get an understanding how the theory can be applied to their own professional environment. By working on a fictional case study, participants learn to recognise, analyse, and value the delays and disruptions caused by recognisable but challenging events.

By the end of the workshop, participants will be able to:

- Understand the importance of a well set up planning in relation to the contract and the analysis of delays and disruptions,
- Understand the importance of records and notices,
- Recognize, analyse and value delay and disruption.


Workshop speakers

Kjeld de Meersseman and Jacob Petrou

With extensive experience in drafting and/or assessing (delay) claims on both domestic and international projects, Kjeld and Jacob are able to share their practical knowledge of real-life examples.

driver trett

Introduction and workshop overview

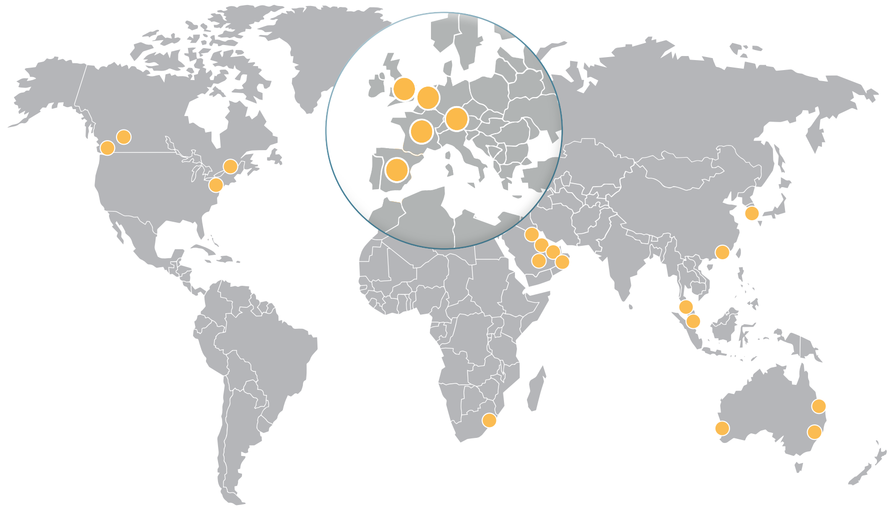
"Very clear. Plenty of opportunity to ask questions."

Who are we?

250+ Staff

18 Countries

5 Continents



A multi-disciplinary consultancy, we have provided specialist dispute avoidance and dispute resolution services to the global construction and engineering industries, for over 45 years.

We have been established in the Netherlands since the late 1980's, and our teams here consist mainly of Dutch and English nationals who have extensive experience in the fields of contract and project management. The support we provide to our clients begins at project inception, pre-contract preparation, tendering and procurement; to the construction phase and managing change, right through to completion and agreement of the final accounts. We do this for both employers and contractors, on projects across the Netherlands and internationally.

As part of a global organisation, we regularly work with our colleagues in Europe, the Americas, the Middle East, and Asia Pacific, enabling us to meet our clients' needs, wherever they are based.

One of our core services to clients is our training offering, which is delivered by experienced professionals who have used contracts on site, either recently or currently. Our advice is focused on practical application, and it is a 'How To' approach that engineers, surveyors, and commercial staff find very useful.

This brochure provides an overview of our workshop on the 8th May. We can provide bespoke training courses for our clients. Please do not hesitate to get in touch with us to discuss your requirements. We will be happy to have a chat.

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BIO

Dr. Khalid Siddiqi is Professor Emeritus of Construction Management at Kennesaw State University, which is one of the fifty largest public university in the US. Khalid has served as the Chair of the Accreditation and Training Committees of the American Council of Construction Education (ACCE) entrusted with the task of granting accreditations to BS & MS Construction Management Programs in the US and Canada. At present Khalid is the Vice Chair of the Board of Trustees of ACCE. Khalid had served as the Chair of Construction Management Department and lead the College of Architecture & Construction Management as College's Interim Dean.

Prior to his academic career spanning twenty-five years, Khalid served the Construction Industry in various capacities in organizations for fifteen-plus years. His industry experience involved working with architects, developers, and contractors around the world in his employment with the World Bank, US Army Environmental Policy Institute, Public Housing Development, Master Planning, managing Building Permitting agencies, and working for Structural Engineering firms.

Khalid Siddiqi
PROFESSOR EMERITUS OF CONSTRUCTION MANAGEMENT, KENNESAW STATE UNIVERSITY

TOPIC

LEADERSHIP IN CONSTRUCTION – INDIVIDUAL AND COLLECTIVE IMPACTS ON CLIMATE CHANGE

Leadership in Construction of projects in the context of Climate Change will be the primary focus of the talk. Individual role of Construction Manager, practices and limitations will be highlighted in the presentation. Personal experience of preparing future Construction Managers, who are sensitive to impacts on environment due to the choices made will be discussed. Strategic changes in curriculum at construction schools, where Construction managers are prepared, will be an important part of the presentation. Few examples of success and failures made collectively by nations impacting the quality of environment will also be discussed.

CITC GLOBAL
Construction in the 21st Century

SMART GRIDS

Webinar with Ballard Asare

MONDAY, MAY 8

1:00 PM - 2:30 PM | LOCATION: R31/A3.04

Solar energy. Wind energy. Examples of sustainably generated energy. This renewable energy is generated in increasing quantities. The share of households that generate their own energy is increasing. But what does this mean for the existing network? What problems do you run into and how can you solve them smartly? Ballard Asare-Bediako explains this in his webinar "The Smart Grids Concept".

MEET THE DEAN

Meeting with Frank Spuij

MONDAY, MAY 8

3:30 PM - 4:30 PM | LOCATION: R26/ENTRANCE HALL AND GARDEN

Meet the dean of HAN University of Applied Sciences, Frank Spuij, and exchange ideas on how to increase or improve cooperation with HAN School of Built Environment. At 4.00 pm this meeting ends and will turn into a gathering with drinks and snacks with guests of the CITC 2023 conference. You're invited to stay.

BIO

Jeroen Rijke is applied research professor Sustainable River Management at HAN University of Applied Sciences. He holds a MSc in Civil Engineering and a PhD in Water Transition Governance. He has been involved with all large water programmes in the Netherlands, incl. the Delta Program, Room for the River and the National Flood Protection Program. Jeroen has worked as a consultant, researcher and project manager on climate adaptation projects in Europe, Australia, Africa and Asia.

TOPIC

THE GRAND CHALLENGE OF KEEPING THE NETHERLANDS FUTURE PROOF

The Netherlands maintains the highest flood protection standards in the world. This is of vital importance because 26% of the country lies beneath sea level and another 29% is prone to river floods. However, there are great challenges to keep the flood protection infrastructure up to standard, including sea level rise and climate change, aging infrastructure, increasingly diverse societal demands regarding functionality, scarcity of building materials, budget constraints, and an aging workforce. In his talk, Jeroen will discuss what is needed to face this grand challenge of keeping the Netherlands future-proof.

Jeroen Rijke
APPLIED RESEARCH PROFESSOR, SUSTAINABLE RIVER MANAGEMENT AT HAN UNIVERSITY OF APPLIED SCIENCES

CITC GLOBAL
Construction in the 21st Century

BIO

Professor Albert Chan is currently PolyU's Dean of Students, Associate Director of Research Institute for Sustainable Urban Development, and Chair Professor of Construction Engineering and Management. He earned his MSc degree in Construction Management and Economics from the University of Aston in Birmingham, and PhD degree in Project Management from the University of South Australia. Before joining the Department of Building and Real Estate of PolyU in 1996, Professor Chan taught at the University of South Australia as a Senior Lecturer and Deputy Head of the School of Building and Planning. He was appointed by PolyU as Associate Head (Teaching) of the Department of Building and Real Estate from 2005 to 2011, Associate Dean from 2011 to 2013, Interim Dean of the Faculty of Construction and Environment from 2013 to 2014, and Head of the Department of Building and Real Estate from 2015 to 2021. He has been an Adjunct Professor in a number of Mainland and overseas universities.

Besides being an expert member of the Engineering Panel of the Research Grants Council, HKSAR from 2015 to 2021, Professor Chan also served as an expert member in the Built Environment Panel of FORMAS, Swedish Research Grants Council, and the Faculty of Architectural and the Built Environment, Delft University of Technology in the Netherlands. Professor Chan was ranked among the Top 2% of Scientists in the World for three years in a row starting in 2020, according to a study by a group of scholars in Stanford University. He was ranked 23rd in the Subject Field of Building and Construction in the World in 2022.

Albert P.C. CHAN

DEAN OF STUDENTS, THE HONG KONG POLYTECHNIC UNIVERSITY (POLYU) | ASSOCIATE DIRECTOR OF RESEARCH INSTITUTE FOR SUSTAINABLE URBAN DEVELOPMENT

TOPIC

DEPARTMENT OF BUILDING AND REAL ESTATE, THE HONG KONG POLYTECHNIC UNIVERSITY

Hospital projects, given their unique characteristics and features, are distinct from other types of construction projects. The development of hospital projects faces several challenges due to rapidly changing user requirements, multiple healthcare policy frameworks, and complexity of process. This study contributes to the Project Management Body of Knowledge by developing a model for enhancing hospital project delivery.

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Construction in the 21st Century

BIO

Eddy has more than 30 years' experience in designing, leading, managing and delivering complex multi-disciplinary projects in the built environment. He is the head of the multi-disciplinary projects department and a member of the WSP Netherlands business management team. In his day-to-day role Eddy leads teams of engineers, project managers, advisers and technicians mentoring and guiding them to successfully deliver integral multi-disciplinary design projects.

Eddy is driven by the belief that good design brings added value to the Client and project. He thinks in opportunities rather than constraints looking beyond perceived project boundaries to develop a greater understanding of the project needs. In this way, Eddy delivers innovative & holistic design solutions to complex problems.

TOPIC

THE EXTRAORDINARY TECHNICAL CHALLENGES OF A UNIQUE HISTORIC RESTORATION

The extraordinary technical challenges faced by WSP / Lievense during the renovation and expansion of Palais Het Loo, a 17th century palace and one of the Netherlands' most popular museums, included jacking up the listed palace buildings, a discontinuous ground water level, a basement constructed underwater and an immovable deadline.

Eddy van Caulil RO

MANAGER MULTIDISCIPLINARY PROJECTS / SENIOR CONSULTANT

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Development of resilience index for safety critical organizations using a fuzzy synthetic evaluation approach

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Abstract

Resilient safety culture (RSC) model earlier developed by authors is defined and categorized into three groups: behavioral, psychological and managerial capabilities. These groups are further sub-divided based on various subcontracts and indicators as found in the literature. Resilient safety culture comprises of the static and the dynamic component which makes it challenging to understand and control. This model thus shows how resilience in organizations can help in defending against uncertainty and safety hazards. A resilience index is needed to quantify and rank the projects in organizations and for relative comparison between sites or projects.

In this paper, resilience index (RI) or safety culture index (SCI) is developed using a fuzzy synthetic evaluation method for safety critical organizations which helps measure the status of resilient safety culture in those organizations. Fuzzy synthetic evaluation (FSE) methodology follows the fuzzy set theory. The index is useful to evaluate various project sites or organizations and compare successfully as it takes care of the fuzziness information available. It can also help in disseminating resources to the weak RI projects. This paper also compares the fault tree analysis approach to fuzzy synthetic evaluation approach and finds that FSE approach is better.

Keywords

Safety, Resilience index, Fuzzy set theory, Maturity model, Safety culture index

1. Introduction

Risk is the potential of an event and activity to produce undesirable negative consequences (Rowe, 1975) and the definition of risk according to Lawrence was risk is the severity and probability of negative adverse effects (Lawrence, 1976). This shows that risk is combination of event's probability of occurrence and its consequences (Rai, Sharma, & Lohani, 2014). In the past, risk assessment, characterization and communication was dependent of traditional probabilistic risk assessment approach, which shows lot of limitations. By enhancing the resilience of the system, this limitation can be reduced (Aven, 2018). This resilience engineering approach does not need to look fully at traditional ways where hazards and uncertainty need to be identified before probabilities are calculated.

In the current approach, the methodology of using RSC uses the indicators or items using a survey which give an overall approach or holistic view of how the system is behaving. This system then gets the resilience level at the indicator, sub construct and the construct level. That resilience level shows the weak links and nodes which need resource allocation. It does not identify risks in a very local sense such as "how will this machine fail in interaction with the human behavior or how this hazard will be dealt with?" but it looks at how the organization as a system is behaving as well as its human resource management. How is the socio technical system behaving? There is off course a connectivity between risk and resilience engineering and that is the resilience engineering helps give pointers where the weak nodes and linkages need to be focused. The survey questions are not specific in nature but holistic in approach which gives it unique sense.

RSC model was generated as seen in earlier studies (A Garg & Mohamed, 2018; Arun Garg, Tonmoy, & Mohamed, 2019). These studies then showed how this model can be quantified. This took into consideration the risk approach where probability analysis was used using fault tree analysis (FTA) and also kept the indicators same throughout and not reducing them. This approach thus gave the probability numbers of those indicators, sub construct and constructs. This is more of the unified approach as described by (Aven, 2018).

1.1 Resilient Safety Culture Model

RSC is a new concept which has been proposed to cover the weaknesses of safety culture. It is a safety culture with resilience, learning, continuous improvements and cost effectiveness (Shirali, Shekari, & Angali, 2016). RSC is based on three factors: 1) Psychological/cognitive capability 2) Behavioral capabilities and 3) Managerial/contextual capabilities to anticipate, monitor, respond and learn in order to manage risks in a resilient organization. Resilience engineering (RE) is added in the safety culture to look at safety in safety-II way.

The psychological/ cognitive capabilities of an organization enable an organization to notice shifts, interpret unfamiliar situations, analyze options and figure out how to respond. It relates to sustaining pressures in a company environment and is a personality trait. Behavioral capabilities comprise of established behaviors and routines that enable an organization to learn more about the situation, implement new routines and fully use its resources. Managerial / contextual capabilities is combination of interpersonal connections, resource stocks and supply lines that provide a foundation of quick actions (Lengnick-Hall, Beck, & Lengnick-Hall, 2011). Figure 1 shows the overall system interaction and behavior of an independent system. Resilience is a characteristic which is added and defined for the system. It takes care of any uncertainty which arise along with safety issues.

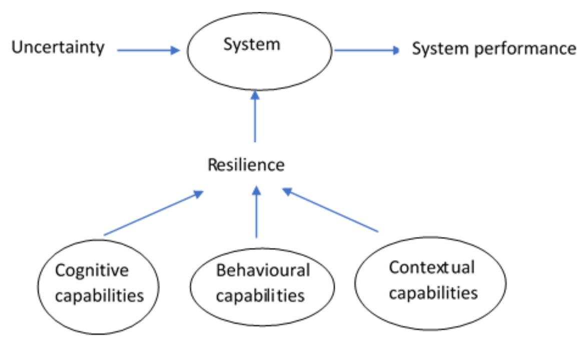

Fig. 1. A resilience incorporated system as perceived by authors

Till now these approaches were used to allocate resources. But we can't compare two different networks and different sites since for example remote site located surveyors may have different perception how they rank or express their views in a Likert scale from 1 to 5. This creates different fuzziness while giving the answers. Resilience index (RI) is calculated by using a fuzzy theory approach to take care of this fuzziness. There are two things to take care while using RI. One is the fuzziness which is there due to the ranking using the Likert scale and the other is the three capabilities (psychological, behavioral and managerial). The drawback using full version of the model without fuzziness as done in earlier studies is that indexing is not done in that scenario so the comparisons cannot be done between different sites and organizations. We use fuzzy synthetic approach to generate the RI.

There are many heuristic techniques such as probabilistic reasoning, neural networks, genetic algorithms, AHP (Analytic hierarchy process) and fuzzy logic which try to find solutions to real world complex problems (Bonissone, 1997). This study uses fuzzy synthetic evaluation (FSE) approach because the resilience or inversely hazard or risk is related to uncertainty and complexity. This FSE method is used in various applications specially in civil engineering such as structural health monitoring, engineering quality, performance evaluation etc.(Wang, Mo, He, & Yan, 2017).

Working with a complex real-world problem require this kind of methodology because there can be qualitative and quantitative indices which can be interacting with each other such is the case in this study. So, one level FSE approach is not possible. Multi-level FSE approach is more suitable to evaluate the complex problems (Wang et al., 2017).

Various authors have used fuzzy synthetic approach. Grecco et al. looked at safety culture assessment using fuzzy set theory (dos Santos Grecco, Vidal, Cosenza, dos Santos, & de Carvalho, 2014). They acknowledged that safety culture concept is hard to measure confirm and manage. The traditional methods used have been lagging indicators measuring activities that have happened already like incidents or accidents. These are all lagging indicators which cannot be used in dynamic environments. Resilience engineering provide the concepts of using the leading as well as lagging indicators together.

Wu et. Al studied the fuzzy synthetic approach to formulate a risk assessment index of electric vehicles supply chain (Wu et al., 2019). Rai et. al developed framework using the fuzzy synthetic evaluation technique to facilitate the identification of the transboundary river basins at risk (Rai et al., 2014). Fugar et al. used FSE to study and quantify job satisfaction level of construction professionals. Boateng et. al formulated a safety culture index using the FSE to quantify the level of safety culture on construction projects in developing countries. It is used in determining the status of safety culture index and it can also be used to compare the relative safety culture levels of different projects for benchmarking purposes (Boateng, Pillay, & Davis, 2020).

2. Fuzzy synthetic evaluation methodology

Fuzzy approach deals with fuzzy logic and membership function. This idea was first introduced by Dieter Klaua in 1965 and L.A Zadeh (Akter et al., 2019). There are three steps to implement the fuzzy logic technique. Fuzzification, fuzzy inference and defuzzification. The relationships between a parameter and the membership function is described by a fuzzy number (Rai et al., 2014). The value of membership function ranges between 0 to 1. The fuzzy number can assume any justified shape according to the information available. Most common functions used to represent linguistic variable are triangular and trapezoidal (Huey-Ming Lee, 1996). Fuzzification coverts the crisp data into fuzzy data or membership function, fuzzy inference combines the membership function with control rules to get the output and defuzzification lead to crisp output of the fuzzy number. Centroid and center of area method are the two most commonly used defuzzification methods (Yager, 1980).

2.1. Model Application

Multiple organizations with sites located remotely and urban areas were surveyed. The surveys were completed by different employees including engineers, supervisors, and managers. There was no limitation on who could fill the survey since the goal is to gauge the perception of all employees working in these organizations along with other attributes about the safety culture. There were 42 items in the survey. Nine items were for "psychological capability", fifteen items were for "behavioral capability" and eighteen items were for "managerial capability". Total forty two items or safety culture attribute (SCA) were inferred using the various indicators of RSC model (A Garg & Mohamed, 2018). Appendix A shows the breakdown of indicators, constructs and sub constructs. Likert scale from 1-5 was used to rate these items, where 1 on the low side or lower expectancy and 5 on the higher side or higher expectancy.

It is difficult to determine the exact probability of occurrence between events (Pan & Yun, 1997). The fuzzy numbers are thus used to deal with imprecise and vague information such as extremely likely, likely, extremely unlikely etc. In our Likert scale, the survey gives five options starting from 1 which denotes very low expectancy (VLE), 2 denotes low expectancy (LE), 3 denotes medium expectancy (ME), 4 denote high expectancy (HE) and 5 denotes very high expectancy (VHE). These linguistic expressions describe the probability of the indicator's occurrence. These linguistic values can be represented by various forms of fuzzy numbers.

3. Methodology

The FSE model follows the following approach (Xu et al., 2010).

Step 1: Establish a basic set of criteria $\pi = \{f_1, f_2, f_3 \dots \dots .. f_n\}$; where n is number of criteria

Step 2: Label the set of grade alternatives as $g = \{g_1, g_2, g_3, \ldots . g_n\}$. This is the scale measurement categories such as Likert scale of 1 means VLE (very low expectancy).

Step 3: Set the weight for each factor component. The weight (W) is found or calculated from the survey using the equation : $w_i = \frac{M_i}{\sum_{i=1}^{5} M_i}, 0 < w_i < 1, \sum_{i=1}^{n} w_{i=1}$ where w_i is weight function of SCA or SCG and M_i is the mean score value of the SCA or SCG, the limit of M is 5 in this study which is the grade

Step 4: Apply fuzzy evaluation matrix for each factor where the matrix is expressed as $R_i = (r_{ij})_{mxn,}$ where r_{ij} is the degree to which gj satisfies the criteria fj.

Step 5. Reach a final FSE results by considering the weight vector and fuzzy evaluation matrix using equation: $D = w_i o\ R_i$ where $w_i$is the weight function for SCA for each SCG, o is fuzzy composite operation and R_i is fuzzy matrix

Step 6. The final FSE matrix is normalized and resilient safety culture index (SCI) for the particular factor is computed using the equation: $SCI = \sum_{i=1}^{5} D * g$

4. Result and discussion

Several preliminary tests were conducted (Osei-Kyei & Chan, 2017) including reliability for internal consistency, correlation matrix, KMO, and Bartlett's test of sphericity to check the appropriateness of the data used in this technique. First, reliability test is conducted using the Cronbach's alpha model. Cronbach's alpha developed by Lee Cronbach in 1951 to measure the reliability or internal consistency. The overall alpha value for the 42 items is 0.945, which is above the threshold of 0.70 (Chan et al. 2010). This indicates high reliability among the survey responses (Chan, Lam, Chan, Cheung, & Ke, 2010).

The correlation matrix measures the relationship among factors based on the partial correlation coefficients. Appendix B shows this matrix. The matrix calculated indicates a strong correlation because their correlation coefficients exceed 0.30 for more than one other variable (Li et al. 2005b; Norusis 2008). The KMO statistic and Bartlett's test of sphericity measure the sampling adequacy. KMO test measure how suited the data is for factor analysis. The test measures sampling adequancy for each variable and for complete model as well. The KMO statistic values vary between 0 and 1, where a value of 0.50 is considered acceptable for a satisfactory factor analysis (Norusis 2008). A KMO value of 0.895 was recorded, which exceeds the threshold (Field, 2013). A KMO value of less than 0.5 is not used, 0.5 to 0.6 is termed "poor", 0.6 to 0.7 is "mediocre", 0.7 to 0.8 is "middling", 0.8 to 0.9 is "good", and 0.9 and above is "excellent" (Chan et al., 2010). This again signifies the appropriateness of the survey data for factor analysis (Chan et al. 2010).

Further, Bartlett's test of sphericity compares the correlation matrix (pearson correlations) to identity matrix . The value of Bartlett's test is large with chi-square value of 3477.6 and its associated significance value is less than 0.05 which is 0.000, indicating that the population correlation matrix is not an identity matrix (Norusis 2008). The principal factor extraction with eigenvalues greater than 1.0, explaining 65.14% of the variance in responses as shown in Table 1. Varimax rotation was used because it simplifies interpretation. Again, this reaffirms the appropriateness of the survey data (Ahadzie et al. 2008).

Table 1. Principal factor extraction for the whole data

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	13.781	32.811	32.811	13.781	32.811	32.811
2	4.698	11.185	43.996	4.698	11.185	43.996

3	2.118	5.044	49.040	2.118	5.044	49.040
4	1.871	4.455	53.495	1.871	4.455	53.495
5	1.399	3.332	56.827	1.399	3.332	56.827
6	1.261	3.002	59.830	1.261	3.002	59.830
7	1.167	2.778	62.608	1.167	2.778	62.608
8	1.067	2.541	65.148	1.067	2.541	65.148
9	0.981	2.335	67.483			
10	0.893	2.127	69.610			
11	0.877	2.089	71.699			
12	0.817	1.945	73.644			
13	0.782	1.863	75.507			
14	0.701	1.669	77.175			
15	0.667	1.587	78.762			
16	0.601	1.430	80.192			
17	0.595	1.416	81.608			
18	0.566	1.349	82.957			
19	0.550	1.310	84.267			
20	0.530	1.262	85.530			
21	0.491	1.170	86.700			
22	0.474	1.128	87.827			
23	0.442	1.051	88.879			
24	0.417	0.993	89.871			
25	0.387	0.922	90.794			
26	0.359	0.854	91.648			
27	0.352	0.838	92.486			
28	0.310	0.739	93.225			
29	0.290	0.691	93.916			
30	0.286	0.682	94.598			
31	0.267	0.636	95.235			
32	0.266	0.633	95.867			
33	0.241	0.575	96.442			
34	0.213	0.507	96.949			
35	0.200	0.477	97.426			
36	0.189	0.451	97.877			
37	0.179	0.426	98.303			
38	0.174	0.415	98.718			
39	0.158	0.377	99.095			
40	0.155	0.368	99.463			
41	0.127	0.302	99.765			
42	0.099	0.235	100.000			

Mean score analysis was used to rank the safety culture attributes in Table 2. Further, to determine the critical attributes of resilient safety culture among the list, normalization was used. Normalized attributes greater than or equal to 0.50 are retained. This selection mechanism has been used by many previous studies to establish the most significant factors (Osei-Kyei and Chan, 2017). With this criterion, out of total 42 indicators or attributes, 15 attributes were deemed critical as presented in Table 3. In this tabulation, we don't use resilience enhancement or weights based on constructs, some studies have used the probability of occurrence with severity to get the significant values of mean and then ranked them. We don't have the severity data thus giving a severity number would create problems. Indexing gives a unbiased outlook of the indicators, later the resources can be allocated based on the psychological, behavioral and managerial approach as found in the earlier studies (A Garg & Mohamed, 2018).

Table 2. Ranking of safety culture attributes-SCA (level 1)

Safety culture attributes	**Mean**	**Rank**	**Standard deviation**	**Normalization**
P1	3.35	1	0.83	1.00
P2	3.06	11	0.90	0.57
P3	3.01	15	0.86	0.48
P4	3.01	14	0.90	0.50
P5	3.07	9	0.71	0.58
P6	2.87	27	0.85	0.28
P7	2.99	17	0.93	0.46
P8	2.76	38	1.08	0.11
P9	2.78	36	0.91	0.13
B1	3.07	9	0.78	0.58
B2	2.96	20	0.88	0.41
B3	3.06	12	0.69	0.56
B4	2.75	39	0.89	0.09
B5	2.77	37	0.92	0.12
B6	2.72	41	0.93	0.04
B7	3.32	2	0.81	0.96
B8	3.24	4	0.88	0.85
B9	3.24	4	1.03	0.85
B10	3.23	6	0.97	0.82
B11	3.20	7	0.85	0.78
B12	2.98	18	0.78	0.44
B13	2.81	33	0.88	0.19
B14	2.69	42	0.92	0.00
B15	2.88	26	0.92	0.30
M1	3.32	2	0.74	0.96
M2	3.09	8	0.93	0.60
M3	2.86	28	0.85	0.26

M4	3.01	15	0.90	0.48
M5	2.89	25	0.91	0.31
M6	2.73	40	1.12	0.07
M7	2.97	19	0.89	0.43
M8	2.86	31	0.90	0.25
M9	2.86	28	0.85	0.26
M10	2.81	34	0.86	0.18
M11	2.94	23	0.88	0.37
M12	2.86	28	0.96	0.26
M13	2.96	20	0.97	0.41
M14	2.80	35	0.96	0.17
M15	2.94	22	0.78	0.39
M16	3.06	12	0.84	0.56
M17	2.90	24	1.02	0.32
M18	2.85	32	0.90	0.24

Normalized value= (Actual value- minimum value)/ (Maximum value-minimum value)

Table 3 shows the selected indicators which has normalized score of 0.5 and above. There are four indicators from the psychological capability, five from behavioral and four from managerial constructs. This shows the resilience information selection using these critical 15 indicators.

Table 3. Attributes mean higher than 0.5 (level 2)

Indicator Naming (SCA) safety culture attribute	Constructs
Sense of purpose	P1
Strong core value	P2
Highly visible moral purpose	P4
Having Attitude	P5
Disciplined creativity	B1
Ability to follow different course of action	B3
Development of useful practical habits	B7
Develop habits of investigation	B8
Develop habits of collaboration	B9
Develop habit of flexibility	B10
Creating robust responses	B11
Respectful interactions within organization	M1
Face to face honest interaction	M2
Exchanging resources	M4
Creating organization structure	M16

4.1 Formulating FSE tool for evaluating resilient safety culture

The multi-level FSE is used to analyze this multilevel decision problem (Ameyaw & Chan, 2015). The first level is the safety culture groupings (SCA) and the second level is the SCG looking at the lower to higher levels. The proposed fuzzy model consists of two levels of membership functions (MFs). Thus membership grades level to level from the lowest indicators and then determines the project resilience index (SCI). The FSE tool is used to determine the objective weightings of each SCG considering the 15 attributes as input variables in the evaluation expression. Subsequent sections illustrate the application of the FSE in developing the SCI.

4.2 Calculating the weights for each SCA and SCG (multi-level)

The weightings for each SCA and SCG are calculated using Eq. (1) based on the mean scores from the survey:

$$w_i = \frac{M_i}{\sum_{i=1}^{5} M_i}, 0 < w_i < 1, \sum_{i=1}^{n} w_{i=1} \quad (1)$$

Where w_i is weight function of SCA or SCG and M_i is the mean score value of the SCA or SCG. For example if we have to calculate the weight of P_1 , equation 1 is used.

$$W_1 = \frac{3.35}{3.35+3.06+3.01+3.07} = 0.38$$

Similarly, the same procedure is adopted to compute the weights for SCA and SCG. Same approach is used to calculate the weightings for the remaining SCAs and SCGs.

Table 4. Weights of SCA and SCG for 15 indicators selected

SCA	Mean of SCA	Weight SCA	Total mean of SCG	Weight of SCG
P1	3.35	0.38		
P2	3.06	0.22		
P4	3.01	0.19		
P5	3.07	0.22		
Psychological capability (P)			12.50	0.26
B1	3.07	0.11		
B3	3.06	0.10		
B7	3.32	0.18		
B8	3.24	0.16		
B9	3.24	0.16		
B10	3.23	0.15		
B11	3.20	0.14		
Behavioral capability (B)			22.37	0.47
M1	3.32	0.37		
M2	3.09	0.23		
M4	3.01	0.19		
M16	3.06	0.22		
Managerial capability (M)			12.47	0.26

4.3 Define the membership function (MF) for each level

The MF are calculated to determine the resilient safety culture index. The MF of the SCA are calculated to get the second level MF of the SCG. We have 5 point Likert scale rating system where 1 is low expectancy and 5 is highest. Using equation 2, we calculate the MF for each SCA. Taking example of P_1 where 1% VLE, 5% LE, 58% ME, 26% HE and 9% VHE.

$$MF_{P1} = (0.01/VLE) + (0.05/LE) + (0.58/ME) + (0.26/HE) + (0.09/VHE) \qquad (2)$$

The MF can be defined as (0.01, 0.05, 0.58, 0.26, 0.09). The MF for the remaining SCA are calculated using the same approach. Table 5 shows the MF for level 1. To calculate the level 2 MF, equation 3 is used.

$$D = w_i o\, R_i \qquad (3)$$

Where w_i is the weight function for SCA for each SCG, o is fuzzy composite operation and R_i is fuzzy matrix. Using the example of Psychological capability SCG, following MF for the SCG is calculated.

$$D_P = w_p \text{ o } R_p = (w_{p1}, w_{p2}, w_{p4}, w_{p5}) \text{ x } \begin{vmatrix} MFp1 \\ MFp2 \\ MFp4 \\ MFp5 \end{vmatrix} = (0.38, 0.22, 0.19, 0.22) \text{ x } \begin{vmatrix} (0.01, 0.05, 0.58, 0.26, 0.09) \\ (0.01, 0.29, 0.38, 0.26, 0.06) \\ (0.01, 0.29, 0.43, 0.20, 0.06) \\ (0.00, 0.17, 0.63, 0.16, 0.04) \end{vmatrix} = (0.01, 0.17, 0.52, 0.23, 0.07)$$

The remaining SCG are calculated in the same way.

Table 5. Membership functions (MF) for selective SCA and SCG

SCA	Weight SCA	MF for selective SCA from lowest to highest (1 to 5)					MF for SCG from lowest to highest (1 to 5)				
P1	0.38	0.01	0.05	0.58	0.26	0.09					
P2	0.22	0.01	0.29	0.38	0.26	0.06					
P4	0.19	0.01	0.29	0.43	0.20	0.06					
P5	0.22	0.00	0.17	0.63	0.16	0.04					
Psychological capability (P)							0.01	0.17	0.52	0.23	0.07
B1	0.11	0.01	0.19	0.57	0.18	0.05					
B3	0.10	0.01	0.15	0.61	0.21	0.01					
B7	0.18	0.01	0.08	0.48	0.40	0.03					
B8	0.16	0.00	0.13	0.46	0.38	0.04					
B9	0.16	0.01	0.15	0.37	0.43	0.05					
B10	0.15	0.01	0.18	0.33	0.45	0.03					
B11	0.14	0.01	0.13	0.46	0.40	0.01					
Behavioral capability (B)							0.01	0.14	0.46	0.36	0.03
M1	0.37	0.01	0.09	0.55	0.30	0.06					
M2	0.23	0.01	0.28	0.42	0.21	0.09					
M4	0.19	0.00	0.28	0.43	0.26	0.04					
M16	0.22	0.03	0.15	0.57	0.20	0.04					

Managerial capability (M)	0.01	0.18	0.50	0.25	0.06

Afterwards the MF of level 2 are substituted in equation 4 to calculate the SCI for each category. Where g is the grades from the Likert scale from 1 to 5.

$$SCI= \sum_{i}^{5} D \ x \ g \qquad (4)$$

Using Psychological capability as example, the SCI is calculated as follows.

$$SCI_{P} = (1*0.01)+(2*0.17)+(3*0.52)+(4*0.23)+(5*0.07) =0.33$$

Table 6 shows the SCI for each construct along with the ranking and coefficients. Behavioral capability is ranked first, then psychological then managerial. Coefficient is calculated as follows (equation 6).

$$\text{Coefficient} = (\text{SCI for SCG}/ \sum SCI \ for \ SCG) \qquad (5)$$

Table 6. Resilience index for each safety culture group (constructs)

Safety culture group (SCG) or construct	**Safety culture index or Resilience index**	**Ranking**	**Coefficients**
Psychological capability (P)	3.17	2	0.330
Behavioural capability (B)	3.27	1	0.340
Managerial capability (M)	3.16	3	0.329
Total	9.61		1

From this study, the SCI for evaluating the resilience index (RI) levels can be expressed as follows as shown in equation 6:

$$SCI= (0.33 \ x \ P) + (0.34 \ x \ B) + (0.329 \ x \ M) \qquad (6)$$

These findings show that most important aspect of resilience in behavioral, then psychological and then managerial. It shows the resource allocation first should go to psychological then behavioral then managerial as per the earlier studies. In this case, behavioral is already highest so the first allocation is psychological and then managerial.

5. Conclusions

The resilience index is designed to create a baseline to enable organizations to monitor the multiple factors that contribute to their resilience. Its primary function is to diagnose strengths and weaknesses and measure the relative performance over time. The resilience index follows a nonlinear relationship where resilience starts with the resilience index from 3.3 and it goes to a 15 maximum. No resilience in the system shows a resilience index of zero value. A company without too much effort and time can jump from a very low base from 3.3 to say 8 then it may take much more effort and time to improve and say reach 12 and perhaps it will take them lifetime to move from 12 to reach 14 or higher. If there is no data from either of the three constructs, then the resilience index is zero. This is how the method functions. The resilience index developed can be deemed flexible in operation at the normalization steps when the user chooses to have a threshold, the threshold can be there or not depending upon the number of calculations the user wants to achieve. The user can choose to select the group in the data for normalization irrespective of the threshold which can be a flexibility to the calculation. Resilience index can help the companies make strategy in dealing with risk. If the company finds a low resilience index, it can see where the level is low and work to enhance the resilience by strengthening that area.

The FSE approach has the ability to do initial filtering to establish critical indicators that requires further analysis (Ameyaw & Chan, 2015). The main goal of this study is resource allocation and ranking the constructs based on the fuzziness information available and also for project comparisons. It takes care of the fuzziness better than any probabilistic techniques (Lo, 1999). Behavioral capability has the highest ranking followed by psychological and managerial. This shows that the resilience information is recorded most for behavioral capability. If we use the fault tree methodology as used in earlier studies for all the data of remote and urban sites together, the following order emerges (Arun Garg et al., 2019). First resilience ranking in psychological then behavioral and then managerial as shown in Appendix C. This shows that indexing is better approach since the fuzziness is cleared between the data available and thus the ranking between the construct changes.

The resilience index is a great tool which can help the industry in reducing incidents and enhance its safety records. More research needs to be done in this area and future studies will look into longitudinal studies where the resilience index predictions of weak areas if rectified can it bring less incidents and higher resilience levels.

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Appendix A

Indicator #	Constructs (SCG)	Safety culture attribute (SCA)	Constructs (SCG)	Sub constructs
1	P	Sense of purpose	P1	Conceptual Orientation
2		Strong core value	P2	
3		Prevailing vocabulary	P3	
4		Highly visible moral purpose	P4	
5		Having Attitude	P5	Constructive Sense making
6		Mindset	P6	
7		Ingenuity to develop new skills	P7	
8		Common language	P8	
9		Situation specific interpretations	P9	
10	B	Disciplined creativity	B1	Learned resourcefulness
11		Combine originality and initiative	B2	
12		Ability to follow different course of action	B3	Counterintuitive agility
13		Engaging in non-conforming repertoires	B4	
14		Have varied and complex action inventory	B5	
15		Have diverse competitive actions	B6	

16		Development of useful practical habits	B7	
17		Develop habits of investigation	B8	
18		Develop habits of collaboration	B9	
19		Develop habit of flexibility	B10	
20		Creating robust responses	B11	Practical habits
21		Ability to spot an opportunity	B12	
22		Developing new competencies	B13	
23		Unlearning obsolete information	B14	
24		Benefit from situations that emerge	B15	Behavioral preparedness
25	M	Respectful interactions within organization	M1	
26		Face to face honest interaction	M2	
27		Disclosure oriented intimacy	M3	
28		Exchanging resources	M4	
29		Sharing tacit information	M5	
30		Cross-functional collaboration	M6	Deep social capital
31		Forging relationships	M7	
32		Relationships with strategic alliances	M8	
33		Bond with various environmental agents	M9	
34		Promote organizational slack	M10	Broad resource network
35		Communicating without getting ignorant label	M11	
36		Communicating without getting incompetent label	M12	
37		Communicating without getting negative label	M13	
38		Communicating without getting time water label	M14	Psychological safety
39		Sharing decision making	M15	
40		Creating organization structure	M16	
41		Members have discretion and responsibility	M17	
42		Replying on self-organization	M18	Diffused power and accountability

P= Psychological capability, B=Behavioral capability, M=Managerial capability

Appendix B

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1	.540**	.496**	.487**	.437**	.330**	.501**	.342**	.285**	.455**	.425**	.256**	0.098	0.133	0.145	0.117	.308**	0.163	0.099	0.095	.416**
2		1	.450**	.641**	.469**	.493**	.502**	.320**	.389**	.541**	.531**	.309**	.236**	.175*	.220**	0.041	.207*	0.092	0.058	0.077	.375**
3			1	.470**	.382**	.370**	.338**	.433**	.291**	.457**	.451**	.270**	0.135	0.057	.193*	0.018	0.094	0.014	-0.002	-0.101	.262**
4				1	.487**	.485**	.581**	.361**	.411**	.516**	.583**	.326**	.320**	0.135	.229**	0.113	.205*	0.035	-0.029	0.138	.457**
5					1	.449**	.540**	.354**	.340**	.596**	.445**	.437**	.326**	.181*	.250**	0.137	.192*	0.115	0.007	0.048	.425**
6						1	.430**	.455**	.469**	.519**	.456**	.322**	.319**	.212*	.292**	0.028	0.110	0.037	0.045	0.046	.271**
7							1	.381**	.487**	.433**	.406**	.272**	.277**	.278**	.357**	0.051	0.152	0.070	-0.071	0.029	.362**
8								1	.440**	.340**	.346**	.252**	0.148	0.083	.214*	0.004	0.061	0.111	0.053	0.044	.262**
9									1	.372**	.376**	.275**	.260**	0.077	.285**	0.047	0.123	0.082	0.026	0.068	.281**
10										1	.564**	.412**	.329**	.287**	.178*	0.044	.228**	.178*	0.113	0.087	.315**
11											1	.302**	.289**	0.104	.258**	0.009	.171*	0.060	0.071	0.089	.422**
12												1	.436**	.341**	.352**	.214*	.191*	.195*	.176*	0.153	.382**
13													1	.441**	.575**	.292**	.290**	.289**	.168*	.181*	.327**
14														1	.549**	.206*	.480**	.436**	.362**	.291**	0.166
15															1	.359**	.488**	.458**	.346**	.327**	.262**
16																1	.378**	.412**	.343**	.433**	0.161
17																	1	.548**	.477**	.579**	0.114
18																		1	.571**	.506**	0.070
19																			1	.542**	-0.022
20																				1	-0.004
21																					1
22																					
23																					
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25																					
26																					
27																					
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	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
1	.296**	0.046	.385**	.502**	.459**	.476**	.230**	.348**	.294**	.189*	.252**	.271**	.348**	0.061	.242**	.180*	.214*	.445**	.479**	.436**	.438**
2	.179*	0.120	.394**	.434**	.521**	.492**	.259**	.292**	.462**	0.155	.352**	.445**	.446**	.170*	.296**	.334**	.315**	.511**	.348**	.378**	.458**
3	.194*	0.012	.333**	.419**	.355**	.418**	.170*	.300**	.259**	-0.028	0.162	.319**	.367**	.213*	.267**	.350**	.353**	.327**	.382**	.392**	.387**
4	.277**	.206*	.467**	.448**	.553**	.531**	.179*	.366**	.413**	0.064	.343**	.418**	.425**	.175*	.456**	.366**	.312**	.477**	.372**	.445**	.441**
5	.219**	.178*	.481**	.370**	.464**	.460**	.204*	.373**	.380**	0.061	.256**	.340**	.392**	.206*	.367**	.405**	.467**	.389**	.419**	.312**	.392**
6	.248**	.235**	.371**	.353**	.446**	.565**	.210*	.339**	.428**	.291**	.298**	.475**	.521**	.280**	.397**	.442**	.445**	.471**	.315**	.379**	.467**
7	.282**	0.116	.382**	.403**	.421**	.511**	.191*	.378**	.388**	.175*	.338**	.282**	.453**	0.133	.415**	.362**	.330**	.421**	.418**	.368**	.441**
8	.181*	0.078	.272**	.221**	.288**	.334**	0.121	.240**	.337**	0.121	0.092	.271**	.379**	0.144	.319**	.336**	.329**	.389**	.366**	.387**	.402**
9	.210*	0.012	.343**	.223**	.358**	.493**	.277**	.270**	.254**	0.001	.227**	.306**	.482**	0.136	.289**	.342**	.362**	.402**	.263**	.305**	.357**
10	.242**	.193*	.500**	.350**	.464**	.573**	.259**	.340**	.447**	0.097	.254**	.496**	.488**	.304**	.452**	.408**	.542**	.546**	.415**	.422**	.420**
11	.278**	.206*	.477**	.430**	.588**	.636**	.247**	.392**	.479**	0.145	.367**	.521**	.581**	.230**	.387**	.471**	.415**	.513**	.511**	.423**	.529**
12	0.054	0.108	.331**	.233**	.253**	.309**	0.093	0.149	.170*	-0.009	-0.033	.186*	0.154	0.162	.199*	.362**	.290**	.290**	.332**	0.081	.201*
13	.409**	.370**	.336**	0.154	.280**	.240**	.255**	.342**	.186*	.254**	.271**	.192*	.276**	.376**	.324**	.380**	.403**	.292**	.183*	0.084	.286**
14	.403**	.436**	.243**	0.044	0.074	0.107	.336**	.231**	0.039	.478**	.372**	0.107	0.099	.403**	0.129	0.143	0.086	.316**	.186*	0.076	0.124
15	.535**	.428**	.377**	.192*	.196*	.197*	.514**	.401**	.219**	.373**	.454**	0.152	.212*	.447**	0.152	.275**	.219**	.337**	.353**	0.138	.320**
16	.216*	0.142	.186*	0.098	0.002	0.032	.277**	.265**	0.022	0.043	0.163	0.042	-0.120	0.131	0.028	0.027	-0.029	0.029	0.112	-0.005	-0.063
17	.525**	.324**	.259**	0.069	0.160	0.122	.510**	.359**	0.118	.340**	.392**	0.016	0.063	.329**	-0.003	-0.013	-0.027	.242**	.205*	0.108	0.065
18	.379**	.218*	0.153	0.097	0.023	0.047	.462**	.285**	0.026	.213*	.290**	0.014	-0.028	.226**	-0.039	-0.011	-0.038	.181*	.177*	0.086	0.025
19	.204*	0.154	0.071	.181*	0.083	0.100	.442**	.219**	-0.050	.226**	.264**	0.021	0.002	.308**	0.019	0.057	-0.059	0.105	.207*	0.068	-0.026
20	.282**	.218*	0.076	0.047	0.051	0.058	.339**	0.131	0.011	.217*	.275**	0.048	-0.134	.288**	0.007	-0.060	-0.144	0.094	0.054	0.032	-0.083
21	.280**	.213*	.455**	.402**	.405**	.401**	.167*	.285**	.252**	0.156	0.110	.302**	.364**	0.030	.289**	.346**	.343**	.310**	.324**	.209*	.359**
22	1	.534**	.394**	0.158	.286**	.255**	.451**	.519**	.265**	.353**	.561**	.216*	.258**	.415**	.279**	.253**	.237**	.344**	.230**	.238**	.293**
23		1	.308**	0.028	.209*	.167*	.274**	.315**	.235**	.297**	.427**	.213*	.243**	.404**	.222**	.220**	.198*	.247**	0.088	0.075	0.153
24			1	.341**	.514**	.471**	.292**	.386**	.400**	0.120	.279**	.387**	.367**	.207*	.452**	.442**	.408**	.417**	.431**	.430**	.488**
25				1	.643**	.538**	.301**	.406**	.337**	0.145	.254**	.366**	.381**	.187*	.388**	.351**	.322**	.383**	.505**	.388**	.365**
26					1	.555**	.286**	.545**	.531**	.213*	.380**	.546**	.557**	.336**	.584**	.439**	.376**	.539**	.541**	.439**	.553**
27						1	.181*	.412**	.523**	0.147	.334**	.462**	.597**	.249**	.394**	.492**	.416**	.523**	.435**	.302**	.483**
28							1	.491**	0.096	.353**	.497**	.191*	.256**	.424**	0.153	0.150	0.161	.323**	.345**	.255**	.271**
29								1	.385**	.354**	.551**	.271**	.410**	.474**	.375**	.308**	.290**	.433**	.436**	.342**	.433**
30									1	0.137	.308**	.424**	.413**	.277**	.432**	.390**	.332**	.498**	.393**	.186*	.492**
31										1	.474**	0.147	.220**	.395**	0.165	0.107	0.044	.300**	.215*	0.109	.301**
32											1	.324**	.387**	.466**	.306**	.184*	.217*	.434**	.299**	.286**	.341**
33												1	.537**	.230**	.563**	.457**	.468**	.479**	.375**	.377**	.435**
34													1	.204*	.488**	.521**	.547**	.558**	.437**	.417**	.505**
35														1	.421**	.473**	.412**	.355**	.300**	0.139	.299**
36															1	.665**	.559**	.476**	.469**	.388**	.497**
37																1	.649**	.410**	.412**	.246**	.466**
38																	1	.477**	.417**	.319**	.449**
39																		1	.592**	.552**	.608**
40																			1	.473**	.586**
41																				1	.435**
42																					1

Appendix C

Construct Group #	RSC constructs	Total data
1	Psychological capability	0.600
2	Behavioral capability	0.596
3	Managerial capability	0.584
	Total resilience level probability (RL)	**0.209**

Assessing the Potential of Adaptive Reuse in South Africa: An Integrative Review using PESTEL Analysis

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Abstract

South Africa is in critical need to structure its future building and construction on the principles of sustainable construction to counteract the negative effects of the building and construction industry on the environment, society, and the economy. Since South Africa became a democratic state in 1994, sustainability has been ingrained in its laws and policies. However, despite the country's adoption of various global frameworks and protocols for environmental preservation, these initiatives have not been fully implemented across all economic sectors. Adaptive reuse (AR) as a concept for sustainable housing development is still in its infancy among South African construction industry professionals. This research examines the contextual factors that affect how AR operations are applied in the building and construction industry, with a focus on the South African private sector. An integrative literature review of a systematic search in the Scopus database, supplemented with a purposive search in Google Scholar was conducted to achieve the PESTEL (political, economic, social, technical, environmental, and legal) analysis. As a result, factors, and variables such as a lack of resources, knowledge, technological know-how, and policies were recognized and contextually described. The government must create relevant enabling legislation, including laws and regulations, tax reductions, and financial and economic incentives for AR initiatives. The data acquired is used as a preliminary step for the design of the necessary tools and models for assisting the private sector in sustainable adaptive reuse initiatives in South Africa.

Keywords

PESTEL analysis, Adaptive reuse, sustainable construction, Potential, Private sector, South Africa

1. Introduction

A shift to sustainable living has become necessary due to the continuous increase in population and the resulting need for infrastructure, which has resulted in the depletion of natural resources and the consequences of climatic pattern changes, global warming, and other apparent negative environmental effect (Abdelfattah, 2020). The construction industry has a significant impact on global resource consumption and since some of these resources are finite and non-renewable, the building sector is directly at odds with the physical environment, which raises the environmental implications of such pressures. As a result, during the past few decades, the phrase "sustainable construction" has become a blanket term for many developers and professionals, with sustainability serving as the foundation for many ideas and conceptions.

The application of sustainable techniques in the building, construction, and functions of an organization requires considering a variety of factors, including social investment, improved efficiency, legal and technical costs, and reduced environmental impacts (Pitt et al., 2009). Lately, South African (SA) governments have emphasized the need for sustainable housing delivery and construction in municipal regulations for individuals and businesses to promote sustainable development. The nation has become more dedicated to achieving sustainable development goals (SDGs) and in addition to participating in international negotiations, it has created a national framework for the transition to a circular economy. As a result, the South African government's implementation of the SDGs within the framework of current regional and national strategic plans, such as the African Union's Agenda 2063 and the nation's own National Development Plan (NDP), emphasizes the necessity of strong partnerships with other organizations (Haywood et al., 2019).

A major category of organizations crucial in this partnership for sustainable development is the private sector property companies (PSPCs) since they play a crucial role in building, construction, and the development of national economies. In South Africa., most investments particularly in the building and construction sector, are made by PSPCs, who make up about 75% of the employed labor force (SA News, 2022). However, due to their limited resources and the cutthroat business climate, applying sustainability concepts among PSPCs poses a significant challenge. Adaptive reuse has received widespread recognition as a key sustainability concept in the building and construction industry and has been used extensively in developed countries (Owojori & Okoro, 2022a). According to Yung and Chan (2012), “adaptive reuse is a new kind of maintainable rebirth of the city, as it covers the building’s lifetime and evades destruction waste, encourages recycles of the embodied dynamism and also delivers substantial social and economic profits to the world”.

The Republic of South Africa (RSA), which is at the southern tip of Africa, is regarded as a middle-income country with a wealth of natural resources and functioning institutions for the economy, politics, and social development (Du Plessis, 2002). South Africa is a nation with a rich history and a number of abandoned heritage places that can be maximized by preserving and at the same time reused efficiently. Adaptive reuse of historic structures can contribute to the creation of a sustainable and healthy built environment (Owojori and Okoro., 2022b) and a positive catalyzation of housing delivery in South Africa if implemented strategically and effectively. To address the issue of applying the adaptive reuse concept among PSPCs in the building and construction sector, it is first necessary to conduct a structured analysis of contextual factors that have an impact on the PSPCs' operations.

This article describes an analysis of South Africa's property-providing companies' current context on adaptive reuse, with an emphasis on the private sector. An analysis based on the political, economic, social, technical, environmental, and legal (PESTEL) structure was conducted to accomplish this objective. The acronym for this analysis, which is frequently used by organizations, stands for the political, economic, social, technological, legal, and environmental factors that often impact business organizations. PESTEL analysis is therefore utilized in strategic planning to examine macro-environmental elements that surround organizations (Marinovic-Matović and Arsic, 2020) as illustrated in Figure 1.

The technique is used for strategic analysis in many different fields such as in assessing transport, waste recovery, oil and gas, business, and more (de Sousa et al., 2022; Song et al., 2017; Capobianco et al., 2021). Related to adaptive reuse, Vardopoulos and Theodoropoulou (2020) used PESTEL to assess the importance of adaptive reuse as a suitable response to the urban sustainability agenda in Greece. Therefore, this study utilizes the PESTEL analysis to study the macro-environmental factors impeding adaptive reuse application in South Africa. This baseline defines the key elements that have an impact on how private sector businesses operate and how it determines their investment choices as a step to conceptualizing indicators for enhanced involvement, responsibility, and environmental stewardship.

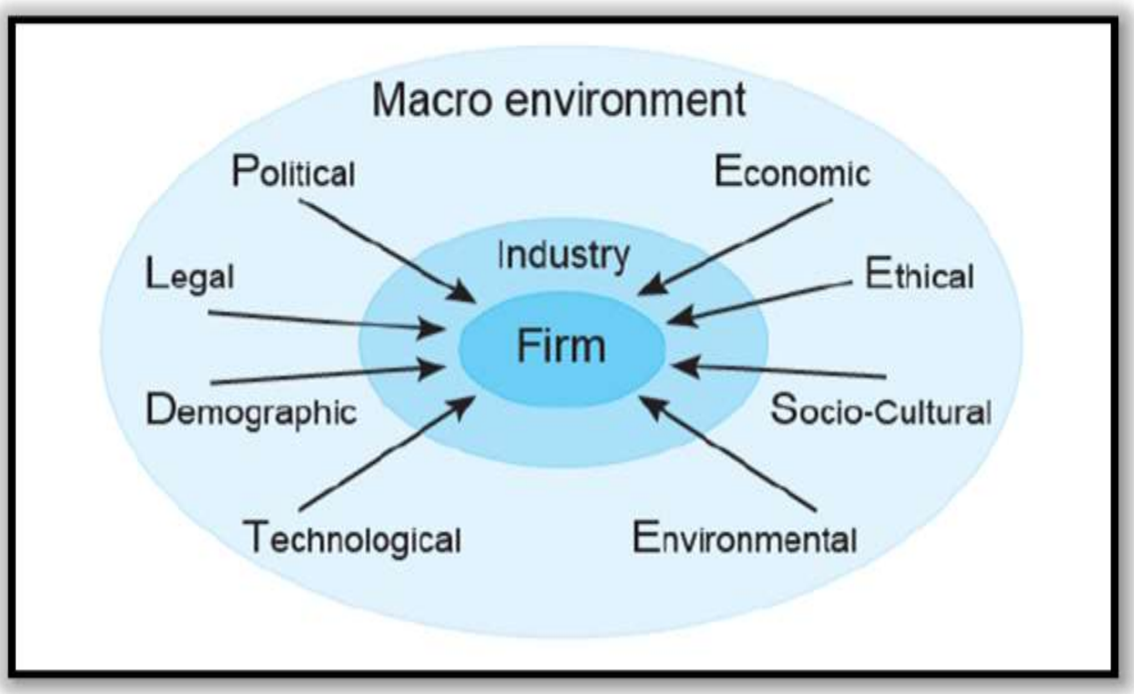

Fig. 1. Macro environment forces affecting a firm (Source: Jurevicius, 2013)

2. Methodology

It is essential to examine several aspects to analyze the context of the SA Private sector property provider comprehensively. These aspects typically fall under categories, such as legal, economic, environmental, or political, which emphasizes the need for careful selection of context dimensions to be considered in this research (Tsilika, 2014). Therefore, the PESTEL analysis was deemed to be more suitable for the current investigation. Given that the PESTEL analysis has been successfully applied as a framework for strategic-level decision-making and has been suggested as a potent method for the creation of credible hypothetical scenarios and innovative business strategies (Matovi, 2020 Thakur, 2021). This approach covers six variables of factors that are external to the private sector (Political, Economic, Social, Technological, Environmental, and Legal), consequently, it enables understanding of the issue from several perspectives and classifications. PESTEL analysis serves two main purposes in assessing the PSPSs in this study: a) enabling the identification of the setting in which the PSPC operates and b) providing data to aid in understanding environments and events that may have an impact on how they apply AR.

2.1. Review Process

This study made use of the integrative review methodology, which was developed by Whittemore and Knafl. It is a review technique that analyzes and synthesizes literature to thoroughly comprehend a particular concept (Whittemore & Knafl, 2005; Marsh et al., 2020). It is particularly helpful for addressing new or emerging concepts trending in various fields (Marsh et al., 2020) Given the current momentum around CE, the topic of AR practices and initiatives in the PSPCs would greatly benefit from an integrative review of the literature as no overview of the body of research has been done on this topic so far.

Moreover, integrative literature evaluations have been shown to provide important contributions to new knowledge by aiding in the initial or preliminary conception of a subject (Klein et al., 2020). The selection of pertinent research through a wide sample frame of varied sources, including theoretical, empirical, academic, and non-academic sources makes choosing to perform an integrated literature review on AR practices in the private sector particularly appropriate.

A systematic search to identify published articles about the application of AR in PSPCs was conducted as the first step in the evaluation process. The Tranfield, Denyer, and Smart (2003)-inspired methodological approach, which provides a review process in three stages: planning, execution, and reporting, was used to organize the sample frame. Considering Scopus is the largest academic database in the world and contains citations to evaluated abstracts from a variety of scientific and research literature, it was selected as the database's source (Tupan et al., 2018)

The search was conducted in the title, keyword, and abstract fields of the Scopus database using combinations of PESTEL-related terms (“political factor,” “economic factor,” “social factor,” technical factor,” “environmental factor,” “legal factor,”). In addition search terms including (“adaptive reuse,” “private sector,” “private companies,” “ construction firm”) were added to limit the search results to a private sector context. The most relevant literature on PSPCs in the area of AR implementation was deemed to be sufficiently covered by these terms. Initially, 242 published papers were found., followed by a screening of the titles, abstracts, and, in certain cases, the full text to ensure relevance to the review at hand.

Following the screening, 33 scientific papers made up the final sample from the systematic search. Since adaptive reuse is a developing field of study and its evaluation in PSPCs may not have been exclusively covered by peer-reviewed publications available through Scopus, it was considered to source for potential publications outside of this source. Consequently, a purposive sampling procedure was combined with this systematic selection of papers to include an additional set of 14 research papers, non-academic papers, and documents from non-governmental and international bodies that were found through a hand search and Google Scholar. The total corpus of resources for the research consisted of 47 papers. This study employed a qualitative content analysis methodology. Results of the analysis are presented in narrative form for each of the six PESTEL contexts. These inquiries aimed to provide a broad overview of the PSPCs context in South Africa, identifying internal and external elements that encourage or inhibit adaptive reuse for housing delivery.

3. Results

The data presented in this section gives a succinct overview of the major factors from the PESTEL dimensions influencing the private sector property providers in the application of AR. The outcome of the examined factors is shown in Table 1.

Table 1. Issues identified from PESTEL analysis (Source: Authors' work)

Political	**Economic**	**Social**
- Political situation - Business ethics - Taxes - custom fees	- Interest rates - Inflation rates - Exchange rate -Fund availability	- Societal culture - Norms -Population dynamics -Beliefs and attitudes - Relevant Skills - Awareness of Adaptive reuse
Technical	**Environment**	**Legal**
- Technical skills - Expertise -Relevant training -Knowledge -Experience of Adaptive reuse	- Environmental processes - Environmental licensing - Green building policies -Energy efficiency requirements	- Policy and building regulations - Approval of reuse - Environmental compliance - Building codes and heritage requirements

3.1. **Political context**

Resolving concerns about the stability of the political situation in the market should take precedence when taking this factor into account. Consideration should be given to business ethics, taxes, levies, and customs as well as the effects of local laws and regulations on businesses (Bullen and Love, 2010; Vardopoulos et al., 2021). Additionally, the market constraints and the tax laws of projects including adaptive reuse should be considered. These factors as illustrated in Figure 2 determine the extent to which a government may influence the operation of the private sector property industry. For instance, many prior housing strategies in South Africa were more focused on political objectives and the enhancement of economic indicators than they were on concerns of quality and sustainability (Ross et al., 2010).

Additionally, political unrest, poor management, political intolerance, public protests, and violence sometimes taint the political climate in South Africa (Rahman, 2021). Many times, these issues impede the growth and advancement of the economy. Thus, gaining the public's and investors' support and confidence considering the political obstacles becomes one of the most crucial factors for private sector investment through adaptive reuse. The degree of political sustainability is naturally impacted by the effectiveness and transparency of the policies (Besley, 2015). Therefore, promoting the private sector's use of the adaptive reuse idea in South Africa will require supportive government policies and strategies at all levels.

Economic context

These refer to escalating prices of building materials, interest rates, the gross domestic product (GDP), income, government spending, the state of the economy, the distribution of funding for infrastructure, and government financial assistance, among others. These factors as reflected in the second tile (economic) in Figure 2 pose a threat to the involvement of the PSPCs in AR projects. The private sector in South African property is mostly profit-driven and concerned with the potential market for the proposed reuse project and the financial sources. The ability of the new usage to generate financially viable activities is of utmost importance (O'Donnell, 2004; Tam &Hao, 2019).

To comply with current building rules, such as those pertaining to fire safety and energy efficiency, reuse projects may require significant capital expenditure (Yap,2013). Additionally, not every façade of a building, such as an industrial one, can satisfy the standards for residential use. The conversion process would require significant, expensive changes.

However, for the project to be attractive to the private sector, it must reach a certain degree of economic efficiency where its expenses are outweighed by its benefits, both tangible and intangible. Therefore, the government must create enticing financial incentives and favorable interest rates to stimulate the adaptive reuse of buildings by private sector property providers.

Social context

The sociological aspect considers all incidents that have a social impact on the housing market and neighborhood. Considering this, it is also necessary to take into account the project's benefits and drawbacks for the local population (Bullen and Love, 2011; Foster, 2020). These elements include population dynamics, cultural norms, and expectations, societal norms, cultural backgrounds, education levels, belief systems, behavioral patterns, user demographics, social customs, a lack of adequate private sector skills, a lack of understanding of the advantages of adaptive reuse, etc. as seen in Figure 2.

The social context of adaptive reuse is somewhat challenging because it has varied connotations for various groups of people (Tweed & Sutherland, 2007), for example, when compared to western, city-style housing, some, for instance, display a low level of acceptance of the traditional styles that are retained to preserve a building's legacy and to foster a sense of community (Ross et al., 2010; Gravagnuolo et al., 2021). By fostering cultural traditions and forms, the reuse of historic structures should guarantee the continuation of social life, which adds to the place's cultural worth UNESCO, 2007). In South Africa, where there is potential to utilize and preserve many traditional and heritage structures, it will be important to overcome this barrier by strengthening awareness of AR benefits for the private sector to leverage this opportunity.

Technological context

They refer to the technicality, skills, and expertise required for renovation, refurbishing, and conversion which adaptive reuse fundamentally requires. Unlike regular construction projects, adaptive reuse building projects demand technical considerations and specialized knowledge of building techniques to achieve sustainability (Bullen and Love, 2011; Sanchez et al., 2020; Foster, 2020). Due to a lack of knowledge, competence, and skills required for sustainable reuse projects, only a few South African construction businesses apply the concept of adaptive reuse of buildings. To develop comprehensive outline arrangements that improve building performance and provide a lucrative investment, the adaptive reuse project design process is also intended to be a joint effort from several stakeholders (Aigwi et al., 2020).

Planning and renovation competencies are necessary for the adaptive reuse of built heritage, which most likely raises the project's cost and duration. In the context of South Africa currently, there is a dearth of expertise in implementing the adaptive reuse technicalities, either in planning or in the renovation work on site. A project component may need to be redone or delayed due to a lack of knowledge and expertise, which raises the cost of carrying out this project (Ngcengeni, 2020). To facilitate more involvement, it is, therefore, necessary to invest in training and capacity development in this area moving forward.

Environmental context

The use of environmentally friendly technologies, energy efficiency, and climate change are discussed in relation to government policy. It includes the demand for greener buildings, and the capacity of residents to purchase repurposed homes, among others. Private property providers incorporating an adaptive reuse approach are still in their infancy in

South Africa, as opposed to other nations like Australia, the UK, and the United States where there have been many successful examples of adaptive reuse and where citizens and clients demand for or to repurpose buildings (Plevoets, & Cleempoel, 2019)

In South Africa, there are laws requiring green building practices, however, architects are cognizant that some adaptively reused buildings may lose their cultural relevance if some environmental design features are added rigorously. However, some have claimed that the green requirements needed to implement adaptive reuse for existing structures might not be attainable (Bullen, 2007; Plevoets, & Cleempoel, 2019) and because any new building structure might not blend in with the current structure, creative and adaptable design solutions are needed (Foster, 2020). To encourage private property sector engagement, it is crucial that the government loosen some of these regulations for some reuse projects that may fit into this category.

Legal context

While there are specific policies that companies uphold for themselves, this factor takes into account all legal issues, both internal and external, that have an impact on the business environment in a country (Yang et al., 2012; Aigwi et al., 2020). For example, legislation and regulatory standards such as zoning, building codes, and byelaws are required for the process of building construction and also, particularly for reuse projects (as in Figure 2).

The fact that South Africa is ensnared in accepting the status quo and has little or no legislation to assist building reuse, while the rest of the world is making progress with sustainable and green buildings, is concerning (Arndt et al., 2021; Odiyo et al., 2022). Due to this basic deficit in planning and policy, as well as the strict adherence to statutory construction requirements, preserving the historic value of the building and adaptive reuse of buildings becomes difficult and complex.

When legacy structures are made to comply with current building requirements, the cost of dealing with regulatory authorities adds an additional cost, and as a result, many heritage buildings have been degraded (Wilkinson et al., 2009; Foster, 2020). When viewed in the context of enabling climate for private developers in South Africa, the policy for adaptive reuse is ineffective. To ensure that functional criteria are followed and that the private sector is more actively involved, suitable legal and regulatory considerations will be necessary.

4. Discussions

The previous section presented a description of the environment in which the PSPCs operate, envisioning possible incidents or factors that would influence their application of adaptive reuse for housing developments. This brief overview demonstrates the significance of PSPCs to South Africa's development. However, these private businesses operate in a complex environment with shifting regulations affecting economic, political, and legal aspects, which negatively affects their operations and contributions and deters private investment and infrastructure development (Smith, 2015; World bank, 2019).

From the policy context, which ranges from restrictions that prohibit the use of adaptation techniques to onerous tax and customs regulations (Besley, 2015; Vardopoulos et al., 2021), to the absence of financial incentives for investment in adaptation (Tam &Hao, 2019), the climate for participation has been so much stiff. The legal framework also shows regulatory complexities, like bylaws or zoning regulations, which discourage involvement (Foster, 2020). Furthermore, in the social and technological environment, the private sector's lack of capability, awareness, knowledge, and skills is equally of concern (Foster 2020; Gravagnuolo et al., 2021).

The private sector offers intriguing prospects for innovation and sustainable growth when well-enabled, but this advantage is diminished by the numerous standards and restrictions that are in place in comparison to other developed nations (Economic report for Africa, 2020). The private sector organization might find it difficult to adapt if it does not comprehend these issues. Therefore, this PESTEL analysis is useful in comprehending the macroenvironment that influences their operations in regard to adaptive reuse.

Given the aforementioned, the majority of problems that the PESTEL analysis in this study revealed pose serious challenges to the private property sector providers in implementing in adaptive reuse concept. Further advice is listed below:

- The current legal framework in South Africa must promote community and private participation in issues including heritage preservation and adaptive reuse.
- Most local planning authorities may relax planning and building regulations under current state and territorial law to promote the usage or preservation of a historic site.
- To motivate the private sector to actively participate in sharing the government's burden of providing housing through the concept of adaptive reuse, tax breaks, and some economic and planning incentives are needed.
- To influence a positive mentality change, more public awareness of the advantages of adaptive reuse for the private, public, and community sectors is necessary.

5. Conclusion

To address the uptake of adaptive reuse by private sector property companies and to set forth directions for increased participation, it is crucial to assess the microenvironmental elements influencing their operations. The PESTEL factors uncovered in this study offer guidance for the public sector on how to increase private sector involvement. This study's findings have implications for urban planning as adaptive reuse can play a crucial role in revitalizing urban areas and preserving historic buildings, thus South African cities can unlock the economic potential of her historic building stock and create sustainable neighborhoods.

Further, the study has an implication for economic development given that adaptive reuse can also promote economic development by creating jobs and attracting investment. Property companies that invest in adaptive reuse can create new jobs in construction, property management, and other related industries. Additionally, adaptive reuse projects can be used to attract new businesses and investment to urban areas, spurring economic growth. This study's findings suggest that private sector property companies can be encouraged to invest in adaptive reuse by reducing regulatory barriers and increasing access to financing thereby increasing the development of new residential and commercial real estate while lowering carbon emissions and promoting sustainable development. Therefore, the findings of this study could be advantageous for both private and public sector property providers. Of special notice is the government, which is in charge of most potential solutions given to eliminate the barriers to more sustainable development.

This study also underscores the potential of public-private partnerships in promoting adaptive reuse. The government can play a crucial role in incentivizing and supporting private sector involvement in adaptive reuse, providing financing, tax incentives, and other policy measures that encourage the uptake of adaptive reuse projects. Thus, by working together, both sectors can create more resilient, sustainable communities. In conclusion, this study's findings suggest that it is vital to recognize the role of microenvironmental factors action in the areas of political, economic, social, technological, environmental and legal and take proper relevant action that can encourage greater private sector participation in adaptive reuse for sustainable development.

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A Regulatory Transformation Case Study in Construction: Past Tense and Future Perfect

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Abstract
New South Wales's (NSW) recent construction regulatory transformation may be an instructive example of Australia's journey toward built environment quality. Until recently, it appeared to be declining. The government and industry published numerous studies focused on several areas, including economics, workforce and quality-of-life; however, these two groups seemed paralysed about the path forward. Therefore, root causes of poor building outcomes emerged. Subsequently, two highly visible apartment buildings were discovered to have many structural, operational and other defects in 2018-19. From this point, a strong focus on improving the industry has steadily occurred, starting in the apartment sector. However, the activity and personality of the Building Commissioner seem to have been the needed catalyst for transformation. This paper documents the journey, using disaster recovery concepts to clarify and draw lessons from these failures. This case study offers approaches and solutions to a state government's reaction that could inform other regulators nationwide.

Keywords
construction regulation, industry transformation, building defects, quality assurance, consumer confidence

1. Introduction
Many Western nations have experienced building disasters and have redoubled efforts toward regulation, inspection and compliance. The great Chicago fire in 1871, the San Francisco Earthquake in 1906, and London's Grenfell Tower fire in 2017 catalysed renewed focus on local governments, if not their national leaders. Two high-rise NSW apartment building controversies were less so, but still notable - New South Wales's Opal Tower in 2018 and Mascot Tower in 2019.

This case study examines the reactions to two apartment construction failures and subsequent regulations in the NSW. Due to the many factors of these residential units, including their generally standardised fit-for-purpose design, omnipresence in all population centres, and funding by sophisticated developers, their quality should indicate the general industry's progress. To explore building regulatory reformation, this paper analysed publicly available information *before and after* NSW's seminal event – the Opal and Mascot Towers' defect crisis. The receivership current estimate is that those rectifications will cost more than AUD 40 million each (9News Staff, 2023).

2. Literature Review
Post-disaster situations always have a gap between bureaucratic procedures and emergent norms. Schneider (1992) asserts that there are many factors in whether this gap closes, thus determining a successful or failed response. Government regulations and statutes enable the response. After a disaster, a widespread reaction among the population takes place. This is called "the milling process" (Turner and Killian 1972). Milling is most pronounced when new conditions are novel and dangerous while the governing institutions' reactions are weak and inaccurate. Once underway, the population forms new types of interactions, including collective behaviour and emergent norms (Quarantelli 1983). However, human behaviour is unpredictable, so "ground zero" interviews of those affected are critical to having the information needed to respond appropriately. If the emergent reaction conflicts with social norms, publicly vocal dissatisfaction may occur, escalating into social unrest and violence (Schneider 1992). In the aftermath of a crisis event, "keynoting" occurs rapidly. It is the selection of key terms, concepts and narratives while others are

discarded (Turner and Killian 1972). Depending on the strength of the personalities involved, leaders and followers, forceful keynoting places the government and other responders on the defensive.

Social media is a new variable in disaster reaction analysis, updating researchers' thinking and frameworks. Heimans and Timms (2018) labelled it "new power" which has a culture, structure and process that, in combination, is unique. Approximately ten participant types are in a social media movement: Institution, Super Participant, Media, Celebrity, NGO, Influencer, Policy Commentor, Platform Steward, Participant and Disinterested. Each is self-explanatory in general.

The built environment has changed considerably over the past few decades in NSW. From the mid-1980s, builders predominantly constructed low-rise apartment buildings on behalf of developers. Designs were regarded as straightforward using readily available standard materials, and the trades were well-skilled, having come through apprenticeship schemes. In addition, a 'Clerk of Works' acting on behalf of the supervising architect ensured quality and compliance were well maintained (MBA, 2019). However, former Treasury Secretary of the NSW Government, Michael Lambert, said the government did not act upon his central review of the home building industry in 2015 and that the government commissioned 18 reports urging sector reform over the past two decades (Cummins, 2019).

Governments in Australia and abroad have reacted to building failings by enacting legislation to curb faulty work and materials. However, governments occasionally ignored advice from industry, academia, and their authorities. For example, the Royal Commissions within Australia have contributed to potential solutions but have been ignored by the government when recommended, as evidenced by Smolders (Smolders, 2016). Additionally, there has been a proliferation of sub-standard projects entering the marketplace with inherent latent defects, as evidenced in the case studies and corroborated by Easthope, Randolf and Judd's study (2012) of strata management in NSW. Adding to this, the High Court decision in the case of Brookfield Multiplex Limited v The Owners – Strata 61288 deemed the builder not to be responsible for economic loss sustained by owners of apartments containing latent defects (Bombell 2014). This decision has been a 'get-out-of jail' card for many developers. The easy entry for these builder/developers has been the ease of securing a builder's licence in NSW. It can be said that it is easier to get a builder's licence than a trade licence in NSW when comparing training for each. Furthermore, in NSW, there is no requirement for any licence to construct a building over three stories (Smolders 2023)

Within the Australian context, with a population of some 25 million, not much larger than some overseas cities, the temptation for coordinated and harmonised regulatory reform was steadfastly on the political agenda in the early 1990s when the Australian Uniform Building Regulations Coordinating Council was introduced (ABCB, 2016). During this period, it was recognised at a State Premiers Conference that the eight State silos of government should come together in what was termed "Cooperative Federalism". Australia could not afford the inefficiencies of different regulations for each State. The drive for a unified regulatory system waned towards the end of the 1990s, and all States introduced private certification, albeit in various guises. In addition, several States have adopted independent building control regimes. For example, New South Wales has the Building Professionals Board (now part of the Office of Fair Trading). Over time, however, this body has come under scrutiny by their respective governments and may be disbanded soon (Lovegrove, 2016).

In Australia, and particularly in the larger States, the transition from municipal certification to private has not been smooth. Like any transitioning process, there are benefits and risks. To identify potential risks and manage them before they become problematic, the benefits potentially should outweigh the risks. With the forecasted rise of apartment construction, the NSW Government released a White Paper (NSW Government, 2013) heralding a new strategy for regulatory control. The White Paper addressed several issues, including building defects, non-compliance, and lack of a building manual. However, a key element was uncovered by Maltabarow relating to the lack of experience by certifiers (Maltabarow, 2013). Maltabarow, who was head of the Building Professionals Board at the time, made a justified statement when he said, "Getting builders to get things right in the first instance would seem to be a better approach than over-reliance on the checking process". This is generally accepted as a principle of quality management. Similarly, comments were made by the current Building Commissioner at an industry function by Morrissey Law at Newcastle on March 24 2021, stating that before his appointment, the Department of Fair Trading, responsible for regulatory control, would spend 80% of its resources on issues about defects, they currently spend 80% to ensure systems are in place before defects can occur. It has taken several years for the regulator to address the defects issues while some apartment developers were unchecked. To get an understanding of the conditions affecting the construction industry, a questionnaire was adopted to ascertain the causation of two major projects, each project had a tender value of $AUD 25 million, and each had rectification costs of around $AUD 25 million, resulting that each project had a completed cost of fifty million Australian dollars after substantial rework. The main causations indicated were the lack of trade and professional skills, the use of non-conforming building products, and poor regulatory control (Smolders, 2016). The following paragraphs will further unpack these causes.

An established pathway for building professionals is the apprenticeship. However, Skilling in NSW has been problematic. Apprenticeships have declined over the past few decades due to mandatory costs imposed by government regulation that has led to a decline in apprentice training. The Master Builders Association (MBA) and the Housing Industry Association (HIA) have departments within their organisations to manage apprenticeships. MBA's viewpoint on apprentices is as follows, "Master Builders advocates that to give added incentive to employers to engage young people in apprenticeships and traineeships, the worker's compensation premium and the cost of any claim, should not be borne by the employer, regardless of the size of the employer, for the duration of the apprenticeship" (MBA 2019). Away from trade training, the student take-up for a degree course in construction management may be encouraging. Still, without the required trades who are appropriately qualified, it could lead to an unsatisfactory outcome, as recently demonstrated in the media. The MBA said, "Master Builders' survey of the industry reveals that the building and construction industry has an aging workforce". The main feeder to replenish licensed builder numbers is through the apprenticeship system, which, at the current rate, will only be able to replace half of the retiring tradespeople and those who leave our industry. Industry studies indicate substantial building and construction work in NSW over the next four to five years. The industry needs to embrace the training of young people through apprenticeships and traineeships so that we have the necessary skills to meet this demand (MBA 2019). Adding to these issues are the Professional bodies akin to the construction industry have lost their shine with dwindling numbers in memberships (Guthrie et al. 2016).

Furthermore, considering the seriousness of the issues raised by industry stakeholders, the MBA called for appointing a single building commissioner or a dedicated Minister in line with other States. The NSW construction industry alone contributes $67 Billion to the NSW economy (MBA 2019) but faces a decline in apartment construction. Why has this decline occurred? This is essentially the result of one policy change. The NSW government has limited the sale of apartments to overseas investors (who provided a catalyst for apartment construction) to curb sharp price increases that effectively excluded local citizens from purchasing their first homes. This policy has significantly impacted what appears to be a glut of residential apartments becoming available for sale and several developments being put on hold. This significant impact on builders and developers is a potentially positive outcome for home buyers. The current NSW Government embarked on an economic recovery strategy when it took office in 2011. A key policy of the NSW government was to facilitate affordable housing that was neglected by the previous government (NSW Planning & Environment, 2019). Their strategy was to generate employment from apartment developments. The sales of these apartments would deliver substantial stamp duty income. However, the outcomes of this policy change have not been considered favourable by apartment owners, as represented by the Owners Corporation Network (OCN) (Smolders 2023).

The reaction to building failures reveals many things about public policy since it is usually under stressful circumstances. The success of this reaction is contingent on the government's understanding of the cause, nature and consequences of the gap between human behaviour and governmental activities (Schneider 1992).

3. Case Study

This paper will use archived material to show the changes made after 2018 that offer a heightened quality (anti-defect) focus. Most examples will be from the regulatory (government) sector and industry. This will show a consistent effort to increase the quality of apartment buildings in NSW.

The notable regulatory action was the introduction of two laws: the Design and Building Practitioner Act and the Residential Apartment Building Act. These were legislated in 2020 but took effect in 2021. The laws were introduced in response to the NSW Government's Shergold Weir Building Confidence Report published in February 2019.

Table 1. New South Wales's Governmental Actions with Their Timeline (Office of Building Commissioner NSW, 2023)

Date	Action	Comments
February 2019	NSW Government Response to the Shergold-Weir Building Confidence Report (which was delivered to the Building Ministers' Forum in mid-2017)	Published two months after the Opal Tower building defect controversy occurred but 20 months after the Shergold Weir Report.

June 2020	Residential Apartment Buildings (Compliance and Enforcement Powers) Act, Effective July 2021	It gives far-reaching but needed authority to the NSW Building Commissioner and authorised officers to take action against defective building work.
June 2020	The Design and Building Practitioner Act, effective July 2021	Whenever construction work on a class 2 building (new or existing) involves a building element or a performance solution, a design practitioner registered (mandatory) under the Design and Building Practitioner Act must prepare regulated designs.
March 2021	Project Remediate	Project Remediate is an opt-in program that provides no-interest loans, free expert program management, and the assurance that when remediation work is completed, the work will be accepted by insurers.
June 2021	Industry Report on Digitalisation of Design and Construction of Class 2 Buildings in New South Wales	Investigation of the Construction Industry's "Digital Readiness" of the class 2 (multi-unit) building sector of NSW with specific emphasis on the production of design and as-built drawings.
October 2021	Research on serious building defects in NSW strata communities	The purpose of the report is to produce precise data on the problem of severe building defects in class 2 residential apartment buildings in NSW.
May 2022	Report: The State of Consumer Confidence – benchmarking consumer confidence toward purchasing class 2 residential properties in NSW	Perception survey of quality, affordability, and other factors.
October 2022	Building Bill 2022 (in Public Consultation Period)	Replaces the Home Building Act and regulates all building work in NSW - residential and commercial - including licensing of practitioners and consumer protection
October 2022	Building Compliance and Enforcement Bill 2022 (in Public Consultation Period)	Supercedes the Residential Apartment Buildings Act and enlarges regulatory compliance and enforcement powers for the building and construction industry in NSW
October 2022	Building and Construction Legislation Amendment Bill 2022 and the Building and Construction Legislation Amendment Regulation 2022 (in Public Consultation Period)	Amends various existing Acts governing the building and construction industry in NSW.

The research report, delivered in October 2021 *on serious building defects in NSW strata communities*, showed the extent of the existing problem. The most commonly occurring significant defect related to waterproofing, affecting 23% of surveyed buildings, followed by fire safety (14%) and 47% of buildings with severe defects were able to achieve resolution. Chillingly, only 15% possessing serious issues were reported to Fair Trading. Additionally, Severe product and installation deficiencies often led to notable financial and emotional stress for homeowners, tenants and strata managers

This holistic transformation initiative, titled, Construct NSW, focuses on six industry reform areas (named "Six Pillars"): regulation, ratings, education, contracts, digital tools, and data and research. See Table 1. This far-reaching approach has significantly transformed the government's and industry's focus to restore the potential apartment purchaser's confidence in residential apartment buildings. These appear to be "keynotes" (Turner and Killian 1972). For example, see actions in Table 2. However, more reforms are desired and planned.

Table 2. The Six Pillars of NSW Construct NSW Initiative

Six Pillars	Intent	Comments
Regulation	Empower the NSW Government to regulate many critical inputs and outputs in Class 2 Buildings (Apartments)	Without government-enforced Quality Assurance and Quality Control, apartment purchasers will sometimes seek other options (rent, lease-to-buy or purchase existing)
Ratings	Gather and disperse critical information about the major players (persons and companies) in any new apartment construction project in NSW	ICIRT assesses building professionals and projects. It is a digital tool backed by the NSW Government, providing consumers, financiers and insurers with independently sourced data to make more informed decisions
Education	Increase knowledge of all participants	Three general thrusts: 1) Construction Industry Doctorate Program 2) Online short courses to upskill workforce 3) Research reports, guides, case studies, templates and other information to keep industry practitioners and construction service buyers up to date with current knowledge, including decision-making processes
Contracts	To identify financial, contractual and governance risks within class 2 building projects in NSW	The OBC commissioned a report by Corrs Chambers Westgarth, which made four recommendations in contract formation, review and administration for more consistent delivery of performing-as-expected projects
Digital Tools	Use of Technology to leverage information gathering, data analysis and quality measurement.	NSW's Building Assurance Solution (BAS) collates product and design compliance certifications for each apartment building to create a body of evidence producing an evidenced-based quality rating for individual buildings for comparison.
Data and Research	Use carefully collected and analysed data and targeted perception surveys supported by objectively reported case studies.	Emphasis on measuring confidence in the industry by consumers, investors and developers. However, many areas will be surveyed, and objective data sets will be collected to plan evidence-based improvement efforts – see below.

The McCrindle Report (2022), *The State of Consumer Confidence* - showed the current perceptions of potential apartment purchases regarding quality, affordability, and other factors. See Figure 1. In its analysis, a calculation was performed for increased consumer confidence (a "sustained boost"). At improvement intervals of 3 – 8% - a range of annual values for a) Sales – AUD 450 million to 1.2 billion, b) Units sold – 690 to 1840, c) Employment gained – 550 to 1250 and d) Tax duty increase – AUD 10.9 to 28.9 million. However, to reach these levels, the industry and government had to understand where confidence resided and the significant issues in the minds of the buying public. From there, efforts could efficiently target concerns. However, benchmarks help, but they, as shown below, are a set of numbers established at one time. The second survey in the future will have relativity to the first. This demonstrates a trend and introduces a new set of investigative questions – "the why".

Figure 1. Selected Results from The State of Consumer Confidence Report (McCrindle Research 2022)

4. Discussion

For many years, the NSW Government did not actively advance construction quality assurance and quality control, thus protecting the public from building defect scandals. Schneider (1992) suggests that the population unfairly blames the government for inadequate reaction immediately after a disaster or a systemic failure at the goading of the mass media. However, given may be an exception, given that the government had a documented history of indifference. So, the population seemed to have taken a libertarian viewpoint of the government's inadequacy in regulated interpersonal transactions in the construction sector.

A well-known strong personality clearly with the population's plight – appears to have been a new variable in this discussion to Schneider and others' assertions. David Chandler was appointed Building Commissioner (BC) – NSW in August 2019 but has been critical of the government's approach to the development and construction industries for years. Before his appointment, he authored many opinions on social media, such as LinkedIn posts and the Fifth Estate articles. This appeared to build credibility within the industry and the public. Subsequently, once named BC, heightened milling appeared to decrease and keynoting increased. Once the building failures in NSW were discovered, the milling process intensified and ebbed. This seemed to be due to the government's immediate reaction but also because of the vital response of the Building Commissioner individually. Keynoting centered around building confidence in the built environment through professional accountability. As a result, the bureaucratic norm was quickly replaced with the emergent standard and maintained.

Chandler's social media activity is notable by the numbers – these are estimated numbers:

- He published 15 multipage articles in the Fifth Estate before January 1 and 8 afterwards, stopping on June 6, 2019.
- He authored 212 posts – many with photographs documenting problems - on LinkedIn (and continues). Approximately 80% are dated after January 1, 2019
- Other social media members' comments on these and his other publications number in the thousands

Chandler appears active in multiple participant types, as Heimans and Timms (2018) described. However, this paper asserts that his behaviour and number of followers qualified in four: (note: The OBC's LinkedIn account shows 48,000 followers, which for Australia is enormous given its 1/15th the size of the US.)

- *Super Participant* – his activity on the subject was pronounced, numerous and articulate on policy and individual construction projects.
- *Celebrity* - his body of work included as Construction Director for Australia's New Parliament House
- *Influencer* – each of his posts drew more than a dozen comments from others
- *Policy Commentator* – he has spoken authoritatively on several general topics that affect the development and construction

The implementation of building regulatory reforms continues in NSW. It appears to have been generated by events in Australia but possibly from others added to the concern, such as the Grenfell Tower disaster. We cannot pinpoint the exact motivation for action after years of advice-seeking but inaction. We suspect this organic regulatory reaction will occur after most building failures; however, it is not confident 100% of the time. However, since a home is the top personal investment, a house owner creates the potential for high emotion and action against the government, including voting against the party in power, vocal protests and destroying others' property.

This may point to an opportunity for reform-minded leaders inside and outside the construction industry. Moreover, as documented failures are publicised, so does the probability that a responsible governing body will react, and address needed problem areas. However, there is always a danger of overregulating an industry to raise costs to unaffordable levels. This is a standard free market concern and a question of balance.

5. Conclusions

Quality is a journey for an individual, an organisation and, in this case, the government of NSW. It is historically evident that watershed moments in construction occur in all societies, but enlightened communities react well to improve inputs, processes and outputs. Sometimes, a group or person is well-qualified and prepared to insert themselves into a crisis.

Part of the triumphant progress made in NSW appears to be due to the initiatives outlined, which are part of the OBC's broader goal to increase public confidence in the multi-storey apartment sector by improving regulatory compliance and increasing professional responsibility. However, this trajectory continues to be a challenge. Bureaucracies tend to be slow-moving and adverse to "collecting enemies"; therefore, reform is not a default but one that is many times forcefully achieved. This force seems disruptive, and people's outrage is the catalyst.

Future research should explore the continuing need to update construction regulations and enforcement, especially the role of political will in implementing such improvements. No doubt, social media is part of the transformation journey. However, any improvement campaign should focus on the government's ensuring minimal quality standards and professional behaviour in concert with the industry. Since the built environment functionality and durability are critical components of quality of life for all, there should be little hesitation.

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Hindrances to the uptake of offsite construction

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Abstract

Pre-manufactured and offsite construction are examples of Modern Methods of Construction identified as having the potential to transform the industry. However, unlike the automobile industry, the global construction industry has not been able to fully exploit and harness the many benefits associated with the use of pre-manufacture and offsite strategies. In nearly all sectors of the global construction industry, far too much construction takes place on construction sites. Several factors hinder the breakthrough required to increase the uptake of offsite construction approaches to levels that significantly impact the industry's performance and outputs. Following a review of extant literature, the most significant constraints that hinder the uptake and increased use of offsite construction strategies are identified. Some of the impacts of these constraints on the industry's growth and development are explored as well as identifying areas for further study. This paper is based on a review of literature only and represents the first stage of a study into the low uptake of offsite construction approaches. Detailed strategies for addressing the constraints are not addressed in this paper. This will be the focus of the next stage in the broader research.

Keywords

Offsite construction, premanufactured construction, hindrances, constraints, modern methods of construction

1. Introduction

Modern Methods of Construction (MMC), off-site manufacture, and prefabrication are among a range of terms variously used in relation to construction innovation (Farmer, 2016). It has been argued that the construction industry faces an almost inevitable decline unless it embraces modern methods of construction (MMC). This is predicated on several factors which cumulatively hamper the growth and development of offsite strategies in the construction industry. Amongst these causes include the effects of the failure to replace retiring workers and low productivity within the industry. The industry can address the skills shortage and encourage greater efficiency and higher productivity in the sector is to embrace and adopting pre-manufacturing (Farmer, 2016). The construction industry generally has a reputation for projects completed over budget and behind schedule. There have been efforts by the leading firms in the industry to improve project time, cost, and quality performance through the use of technological and commercial industry innovations such as Building Information Modelling (BIM) and collaborative supplier engagement models. Whilst these initiatives have yielded significant gains, they have unfortunately failed to counter the effects of the growing challenge of industry skills shortages or reverse the trend of poor project uncertainty and low productivity (KPMG, 2016).

To address challenges within the industry, there needs to be investments in and promote innovation across the entire industry. There is no suggestion that MMC typologies, such as pre-manufactured and offsite construction approaches will address the many problems faced by the industry. However, these novel approaches present several benefits which provide a compelling case for their use by the industry for the industry's benefit (Ofori-Kuragu & Osei-Kyei, 2021). Increased use of offsite construction products will require smaller workforce numbers on site to assemble pre-manufactured elements. This in turn leads to overall safer construction sites. Whilst there is already a sizable proportion of lower-level pre-manufactured components such as windows, outer fences, and simple flat-pack 3-D structures, etc. used in construction, the levels are not sufficient.

Further research is required to explore the reasons for the low uptake. To enable the industry to exploit the opportunities presented, there needs to be coordinated stakeholder action (RIBA, 2016) to address these challenges and thus promote the uptake of MMC and premanufactured construction. Again, there must be increased investment in MMCs and in promoting these solutions to enable more clients to adopt these for their projects(Farmer, 2016).

2. Methods

This paper is the first stage of research into the constraints that hinder the uptake of offsite construction methods. This paper has been developed based on a review of recent literature on the subject with a focus on journal publications, conference papers, industry reports from the UK construction industry, and research outputs by some of the leading organisations in the field of offsite and premanufactured construction. The industry reports reviewed were mainly developed from surveys of their memberships which make them representative of larger sections of the industry.

In this paper, the main constraints from the review have been identified in Table 1. Some of the causes and impacts of the identified are discussed in this paper. In the next stage, a systematic review of literature will be undertaken to identify solutions to the identified constraints. An industry-wide survey of professionals with experience in OSC projects and module manufacture to explore their views on the solutions to the most common hindrances to the uptake of **OSC.**

3. Evaluation of Literature

3.1 Offsite Construction

The construction industry faces a race against time to embrace modern methods of construction (MMC). The Farmer Report argued that adopting pre-manufacturing as a core element of offsite construction offered the only way forward for the industry to address issues with low productivity, and skills shortage and encourage greater efficiency (Farmer, 2016). Offsite construction as a generic term incorporates the manufacture and pre-assembly of components, elements, or modules which are then installed into their final location on construction sites. It is one of the main approaches within the overarching terminology of Modern Methods of Construction (Smith *et al.*, 2015). Offsite construction has also been defined as the prefabrication, modularisation, and standardisation of construction processes and assets within controlled factory environments (KPMG, 2016). This part of the construction process carried out away from the building site can be in a factory or a specially created temporary production facility close to the construction site (RIBA, 2016).

In the true sense of the term, offsite construction “involves substantial factory manufacturing intervention to add to project value, with the percentage of on-site added value to the final construction value at project completion expected to be less than 40% (CIC, 2013). Offsite construction also produces elements or modules and offers an alternative to the status quo in the construction industry and promises transformative improvements in time, cost, quality, greater predictability, and safety (KPMG, 2016). Offsite construction thus broadly incorporates the same concepts integral to the key stages of construction industrialisation. The use of prefabrication in construction became more popular in the 1900s (Autodesk, 2019). Whilst, not a new technique, it is becoming easier to use as a result of advanced modelling techniques which enable contractors to use standardised elements using bottom-up approaches in infrastructure and building construction (Hussein et al.,2021). Prefabrication is adaptable to diverse types of structure and has the potential to help achieve important levels of standardisation, providing a key cornerstone to unlocking manufacturing-style productivity levels within the construction industry. If this were to be achieved, buildings could be manufactured in low-cost manufacturing centres and shipped to destinations anywhere in the world for final assembly (Autodesk, 2017). Such innovation could significantly improve the competitiveness of the construction industry (Sutrisna et al., 2022).

3.2 Hindrances to the uptake of offsite construction

Despite a broad acknowledgment of benefits associated with offsite construction approaches, offsite construction contributes only 7% to the UK construction GDP. Legitimate questions continue to be asked about the low uptake of offsite in the UK construction industry. Some of the barriers to the increased uptake of offsite in the UK construction industry include the prohibitive cost of entry, the need for fully front-loaded engagement with suppliers, a lack of confidence in product quality, and a lack of certification and standardisation of products (KPMG, 2016). Other typical obstacles include the overall poor image of the construction industry in society arising from misconceptions held about the quality and prices of products. Perceptions about the limited scope for customisation and the demand by many clients for individual solutions also discourage the use of standardized processes and components. Again, the limited experience amongst construction workers of the application of prefabrication especially in high-rise projects, and the generally increased risks involved in committing to particular off-site suppliers at a time the sector is in its initial stages of development with limited available alternatives (WEF, 2016).

Given the prohibitive costs involved in establishing factories for offsite manufacturing, the irregular nature of construction demand thus leads to an underutilization of the prefabrication factory space (WEF, 2016). Pinsent Masons (2017) identifies the huge upfront investments in the development of new factories for the manufacturing of modular products as a major barrier to the increased use of offsite solutions. Another criticism of modular construction is the fact that modules may be manufactured offsite and transported from distant locations to site for installation. It has been argued that this is not sustainable and does not utilise local labour (Pinsent Masons, 2017). Despite this criticism, there are instances where restrictions on site and a lack of ample space, and labour shortages make this unavoidable.

In cases where factories are located far away from construction sites, another constraint is transportation costs. It can be expensive to transport manufactured components from factories to sites where transport links are not well developed whilst some communities may oppose the transportation of huge offsite manufactured components through their localities (Choi et al., 2019).

Again, it can be a problem handling large, prefabricated components in space-constrained construction sites. Technical specifications from owners may also be a barrier to the wider use of standardisation, modularisation, and prefabrication (Wilson et al.,2019). The highly detailed designs required early on in modular construction minimises the ability to influence the design. Another major constraint to the use of modular construction is the costs associated with such developments (Pan and Sidwell, 2011). Whilst repetitive designs enable economies of scale, unfortunately, it leads to uniform and sometimes "boring" buildings. Designing for manufacture as happens in modular construction produces inflexible, expensive ugly, identikit buildings that may not appeal to many potential buyers (Jaillon and Poon, 2010). Also, in some places, local regulatory requirements reduce the cost-effectiveness of standard factory-made solutions, thus making offsite solutions more expensive and less competitive (CIC, 2013). The housing sector's price sensitivity presents significant commercial challenges to increasing the use of offsite construction solutions in the house-building sector. Where there is a demonstrable business or project case, there is evidence that the industry is receptive to the use of offsite technologies. (CIC, 2013). An example of this is the extensive use in the UK construction house building industry of factory-manufactured truss-rafters and timber frame systems.

Durdyev and Ismail (2018) concluded that in the particular local context, skills shortage was the most significant barrier to the increased use of offsite construction solutions. however, it has also been argued that demand from the industry presently is insufficient to enable the opportunities arising from economies of scale through mass-production techniques to reduce unit prices, especially in the private sector (CIC, 2013). Other constraints to the widespread use of offsite solutions included a lack of a universally acknowledged definition for offsite and MMC, a lack of sufficient knowledge within professional ranks in the industry about the offsite solution, and a lack of R&D resources on offsite construction. There was also a lack of support from warranty bodies, lenders, and surveyors concerning offsite products (HfS, 2015).

Another aspect involves the interface between designers and manufacturers. Whilst appropriate house warranty schemes may provide warranty protection against insolvency and default of developers and contractors (BSA, 2017), the issue of how lenders to developers and house buyers will obtain warranty protection against module manufacturers is a grey area that needs to be explored (Pinsent Masons, 2017). The interfaces in the design process need to be clarified as to whether manufacturers are designers or simply building to specifications generated by other entities. Again, there is a negative effect on cash flow as contractors had to invest in offsite manufactured components in advance of receiving orders from clients. This would lock up contractor capital or compel them to borrow at a cost. The study concludes amongst other things that any movement towards offsite must be demand-led and argues that the business case for offsite is yet to be established (HfS, 2015).

Housebuilders are risk averse and would typically not adopt the use of novel technology unless there was a powerful commercial justification for taking on that risk. Again, the long lead-in associated with off-site fabrication means that payments will need to be made by contractors before the delivery of goods to the site. In cases where off-site manufacturers are based abroad, issues around shipping risk, and marine cargo insurance need to be sorted as well as the apportionment of the risk of delay which may arise from shipping as argued by Pinsent Masons (2017). In addition to this, the strong bargaining position of modular suppliers is acknowledged.

Table 1 Summary of hindrances to the uptake of OSC from literature

Barrier	Source
High cost of entry	KPMG (2016), HfS (2015), Agapiou (2022)
The need for fully front-loaded engagement with suppliers	KPMG (2016)
A lack of confidence in product quality,	KPMG (2016)
A lack of certification	KPMG (2016)
A lack of standardisation of products	KPMG (2016), WEF(2016),
Limited experience among construction workers in the application of prefabrication especially in high-rise projects	WEF (2016)
Increased risks involved in committing to particular off-site suppliers	WEF (2016)
Irregular nature of construction demand	WEF (2016)
Overall poor image of the construction industry in society	WEF (2016)
Perceptions about the limited scope for customisation	WEF (2016)
The demand by many clients for individual solutions	WEF (2016)
Local labour and sustainability implications of transporting offsite products	Pinsent Masons (2017)
Transportation costs	Pinsent Masons (2017)
Handling large, prefabricated components in constrained construction sites	Pinsent Masons (2017)
Technical specifications from owners	WEF (2016)
The highly detailed designs required early on in modular construction	WEF (2016)
Production of inflexible, expensive ugly, identikit buildings that may not appeal to many potential buyers	Pinsent Masons (2017)
Local regulatory requirements which reduce the cost-effectiveness of standard factory-made solutions	CIC (2013)
Housing sector's price sensitivity	CIC (2013)
Skills shortage	Durdyev and Ismail (2018)
Insufficient demand from the industry to enable the opportunities arising from economies of scale through mass-production techniques to reduce unit prices, especially in the private sector.	
Little likelihood of potential gains in the house-building sector arising from mass production on a scale that justifies additional investments in manufacturing costs associated with the offsite solution	CIC (2013)
A lack of a universally acknowledged definition for offsite and MMC,	HfS (2015)
A lack of sufficient knowledge within professional ranks in the industry about the offsite solution, and a lack of R&D resources on offsite.	HfS (2015)
Lack of support from warranty bodies, lenders, and surveyors	
overall costs which were seen to be higher in the case of offsite construction.	
Another aspect involves the interface between designers and manufacturers and the effects on house warranty schemes	Pinsent Masons (2017) BSA (2017)
Lack of clarity between manufacturers are designers	Pinsent Masons (2017)
Clarifying responsibilities for specification, on-site design, overall design of a scheme, and associated infrastructure need to be established.	BSA (2017)
Negative effect on cash flow due to contractor investment in offsite manufactured components	Pinsent Masons(2017)
Lack of a business case for offsite	HfS (2015),
Risk averseness of Housebuilders	(CIC, 2013).
Long lead-in associated with off-site fabrication	
Issues around shipping risk, and marine cargo insurance	
The strong bargaining position of modular suppliers is acknowledged.	
The apportionment of the risk of delay	Pinsent Masons (2017)
Insolvency risk	
Risks arising from bespoke design associated with modular construction	Pinsent Masons (2017)
The unwillingness of D&B main contractors to accept risk	(Pinsent Masons, 2017)
Lack of data on producer capacity to cope with increased demand for offsite construction inputs.	KPMG (2016)
The issue of the sub-contract terms in relation to pricing, payment schedules, and design responsibility	Pinsent Masons (2017)
Lack of compelling empirical evidence for the end-demand market	Farmer, 2016

Evidence from Agapiou (2022) indicated that cost-related barriers were perceived to be the most significant barriers to OSC use for Housing Associations. This was followed by the capacity of suppliers and end-user preferences for traditional construction. An acknowledgment that in the event a contractor opts to manufacture their modular units, they bear the design and construction risk with no recourse to any third parties. Where a contractor or housebuilder buys modules from a third party or enters into a joint venture with their party, a greater portion of the overall value of the development will be situated in that single contract (Pinsent Masons, 2017). In this case, in the event of problems arising concerning the modules, the purchase contract or joint venture agreement should provide suitable protection to the contractor or housebuilder (Goldhadr et al., 2022). Another obstacle to the use of offsite solutions in the housing sector is a lack of appreciation by the offsite sector of how the house-building industry works (Gusmao et al., 2020)FF. Most offsite manufacturers thus concentrate on sectors of the construction industry with relative ease of entry (CIC, 2013). The lack of credible evidence of the value of offsite at project, portfolio, and asset whole-life levels is a major issue as evidenced in Goulding et al. (2012).

4. Discussion

Offsite construction, premanufactured construction, and prefabrication are some of the most popular examples of the broader family of Modern Methods of Construction (MMM) which are generally acknowledged to have the potential to transform construction. It has been suggested that the very existence of the construction industry could be hinged on the uptake of these technologies. Despite several studies and compelling evidence in literature of the benefits of offsite construction, the uptake of these technologies is low. To enhance the uptake of these transformative technologies, the constraints which hinder their uptake need to be explored and innovative solutions found to address the constraints enhance their uptake. Some of the constraints are related to cost, quality, risks, economic justification, warranty, supply, and demand. In addition to the commonly known barriers associated with Modular Construction, There are critical issues relating to insolvency risk associated with modular construction owing to a substantial proportion of a project's turnover resting with one sub-contractor. Bespoke design associated with modular construction can add to the risk and increase costs and potential delays. Bond packages including parent company guarantees may be used to address this risk.

Despite the best efforts of pioneer businesses in the premanufactured sector, there is not yet a successful business case established for this construction approach. Like many new products and process innovators, compelling empirical evidence for the end-demand market which could lead to large-scale adoption of this approach is lacking. Viewed broadly quantitatively and qualitatively against the traditional site-based labour-intensive approaches, including comparisons of variables such as speed, certainty, quality, smart technology possibilities, capex, and opex, there is a lack of robust quantifiable evidence to justify a need for pre-manufactured construction (Assaad et al.,2022). This reduces its appeal to both Clients and Main Contractors as the benefits case for pre-manufactured construction is difficult to demonstrate. The evidence from the review in this paper does not suggest the superiority of any of the identified constraints. Whilst there is some evidence that cost-related factors appear to be the most important in relation to residential developments, additional work is required to establish whether this applies to the rest of the industry. Some additional investigation of the value of offsite at project, portfolio, and asset whole-life levels will also be beneficial in seeking to address the constraints which hinder the uptake of offsite construction approaches in the construction industry.

5. Conclusions and recommendations

This paper asserts that despite the acknowledged and obvious benefits associated with offsite construction approaches, the uptake continues to be low globally. Some of the common hindrances relating to cost, quality, risk, demand, and capacity are identified in this paper. In addition to these, there is limited quantitative evidence available to show that offsite manufactured assets do offer whole-of-life cost savings as compared with onsite constructed assets. Owing to the industry's focus on reducing total costs (totex), it will be helpful to the industry to find data sets to demonstrate the whole life value offsite. This will provide credible evidence for the value of offsite at project, portfolio, and asset whole-life levels.

References have been made in this paper to previous studies which suggest excess capacity by offsite manufacturers In the absence of reliable recent data on manufacturer capacity, it is recommended that further study be undertaken into UK offsite manufacturer capacity to determine the true state of producer capacity to cope with increased demand for offsite construction inputs. As reported in KPMG (2016), "a clearer picture of UK offsite factory capacity and utilisation is needed to help clients and investors better exploit latent capacity in the market". Also, the issue of the sub-contract terms in the context of the main contract with which the contractor has to comply has to be investigated and interrogated to find the main contractor's view of this. Finally, whilst much of the existing literature, especially industry reports focus on the use of offsite methods in residential developments, some additional work on other uses, for example in high-rise developments will be beneficial.

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Strengths Opportunities Weaknesses and Challenges (SWOC) analysis of Online Education for teaching Urban Planning and Construction Management in Pandemics

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Abstract:
The Novel Corona Virus and its infection COVID-19 has played an unprecedented havoc with the world. Education sector in general and Higher Education in particular has received the big shock as the need for physical distancing has forced the closure of these institutions. The Challenges of poor access, low speed of internet, geographical diversity, and poor socioeconomic condition of the people in the development countries, further multiply these challenges. Teaching of professional programs like Engineering and Construction Management becomes even more difficult. In this mixed mode research based on questionnaire survey and Focal Group Discussions (FGDs) with the students, faculty and senior staff, Strength, Weaknesses, Opportunities and Challenges (SWOC) analysis has been carried out, to assess the Online Education and eLearning in professional education with special reference to teaching of Construction Management education and research. The results were used for improvement of the systems, processes and capacity of the human resource for acceptability of the online education in the COVID-19 scenario.
Keywords: *COVID-19; Physical distancing; Higher education, Construction Management*

1. Introduction:

i. *COVID-19 and its impacts on global higher education:*

The lockdown due to COVID-19, has forced the educational institutes for more than a year now and all levels of education including elementary, secondary and post-secondary have been affected (Saavedra J, 2020). This uncertainty has been growing in many parts of the world, as the third wave of the infections is more lethal in the developing world, where vaccination has not been very effectively administered (Chinazzi *et al*., 2020; Hopman, Allegranzi, & Mehtar, 2020; Kraemer *et al*., 2020). After a pause of almost one year through extensive vaccicantion programs around the world, the pandemic is reported to resurface in some parts of the China and different new variants are experienced by thousands of people. The higher education has been affected in many ways. Severe anxiety, depressions and mental ailments have been reported in many parts of the world, due to continuous isolation of the students. The welfare of the students, normally acquired at the schools, through socialization, sports activities and interaction with the teachers and class fellows has been severely disrupted with the long term closure of schools and Universities (Wang.G *et al*,2020; Nicola *et al*,2020). The higher education at global level has been receiving a number of socks. The decline of students' enrolments, disturbance of academic calendars postponement of conference and workshops have led to serious decline in the Universities revenue (Ogunode,2020). Though the vaccination against COVID-19 has been intensified during last 6 months across the world, yet educational institutes are expected to remain either closed or partly closed till Fall 2021 till Dec 2021.

ii. *Various options for teaching and learning during COVID-19:*

Variety of platform for teaching and learning have been explored during COVID-19. These include online education, eLearning, Distance learning, hybrid learning, collaborative learning, Team Based Learning (TBL) and blended etc. (Gwein V,2020). With the advent of modern technologies, the online and virtual education has been increased many times during last few decades and it was mainly used to supplement the existing face to face teaching and learning ((Nic.B and Frederik A, 2020). During the COVID-19, the entire world has to switchover suddenly to online education, for which both the faculty and students were not ready in fact, hence the satisfaction of students in design schools for use of online education remained sparse and varied. The major concerns like the platform adoptability, platform privacy, platform service and maintenance as well as the system quality, interaction quality, service quality, and platform availability were shared by students and faculty (Tingguie C *et al*,2020).

iii. Health and Urban design in post COVID-19 era: The current focus of the post COVID-19, new normal is mainly over the health and wellbeing of people. A number of associated harmful issues related to human health include, depressions, loneliness, shocks, domestic violence, insomnia etc. (Dore 2020; Douglas et al. 2020). The positive sides of the pandemic include, reduced air pollution, noise level, less traffic jams, more physical exercises and use of cycling etc. The human health is defined as "a state of complete physical, mental and social well-being". Hence the urban design, can play a pivotal role to address the contemporary health challenges while using interdisciplinary solutions (Azzopardi-Muscat et al,2020). The *health in all policies* or *design for health approach* has further, compelled the urban design professionals, to have human health as the top agenda for all designs (Rice, 2019). The treatment of diseases has been shifted from traditional prescribing of medicines to "social prescribing", "Nature prescribing" or "Spatial prescribing" through better urban design. Hence urban design can be involved in the modifying, retrofitting and regenerating existing urban areas, so that the built environment can have healing and regenerative impacts on human health (Marsh and Rice, 2020). In this context the basic dimensions of urban design to ensure health may include, i. Morphological dimension ii. Perceptual dimension iii. Social dimension iv Visual dimension v. Functional dimension and Temporal dimension (Carmona *et al*, 2010). In the post COVID-19 world, there is a high need of health related evidence based urban design, to mitigate the impacts of pandemics. The urban design as a result has taken a new paradigm shift, which is portrayed to develop amicable relation between nature and health (Rice L.2020). The post COVID-19 new era has posed many questions to the contemporary urban design approaches, which has forced the designers for more urban resilience. The need for physical distancing and isolation has advocated polycentric cities rather than monocentric cities and the availability of daily needs on walkable distances in the neighbourhood becomes more important, as the people would avoid to travel in public transport to rush areas. The design of large parks and large dwelling blocks will also need rethinking, as such places don't have private spaces. The social distancing during pandemic have further isolate the societies, as the high reliance of the people on IT based networks have already fragmented the society. Hence the major focus for urban design teaching will be specific curriculum on *Socio-Spatial Justice*. This will require redesigning the relevant courses and practicum. The post COVID-19, urban planning and designing pedagogy will need to be focused on rebalancing the ecological system in a better way. The concept of "*Live in Harmony with nature"* appears to be more dominant in the post of COVID-19 (Attenborough 2019).

iii. Challenges of Teaching of Engineering and Construction Management in Pandemics: The imminent stress due to isolation and physical distancing of students in the post COVID-19, has led to many psychological, social and physiological issues. Design education has deep involvement of the students with the faculty and peers in development of the projects, assignments mostly in studios and their physical interaction is maximum during the classes and lab works. The sudden restrictions of physical interaction, through a series of lock downs, spanning for more than a year now, has serious repercussions on the teaching and learning of deign courses. Online support systems were set up by various Universities across the world for Engineering and Design programs, but these solutions are not sufficient to provide, the desired emotional and personal support required to reduce the pressure during COVID-19 (Rooij.R *et al.*,2020). Though, the more informal way of learning becomes difficult during online teaching, yet it has been observed that some preparatory work can be more rigorously done online. In the post COVID-19 era, blended learning model incorporating face to face on campus and online education may be used as an alternative but in both cases, the students' engagement becomes more important for teaching of design courses. The sessions have to be content rich in both the cases, so that the effectiveness of the blended system can be resulted.

In this research, the challenges and opportunities in teaching of design courses in Engineering and Construction Management programs have been assessed on the basis of literature review and questionnaire survey of the students of the design and Engineering schools and results have been shared.

2. **Problem Statement and Methodology**: Teaching and education of design based Engineering and Construction Management programs are faced with serious challenges after shifting of most of the teaching & learning to online modes during and post pandemic era. In this research questionnaire survey was conducted to Engineering and construction Management students, through google form. The questionnaire mainly involved assessment of the perceptions of students and faculty about the use of online and blended education model for teaching of design and labs related courses. The survey was followed by online interviews with the faculty to assess their preparation and adaptability to the online & blended education during COVID-19.

3. **Results:**

3.1: Use of various platforms for teaching of Engineering and Construction Management courses:

A variety of technological platforms for teaching and learning were used, which included Corporate E-mails (35%), Webinars (20%), messengers (5%), Web and Cloud Services (10%), Model Simulations (15%), Labs not conducted (10%) and others (5%). The distribution has been given in Fig 1.

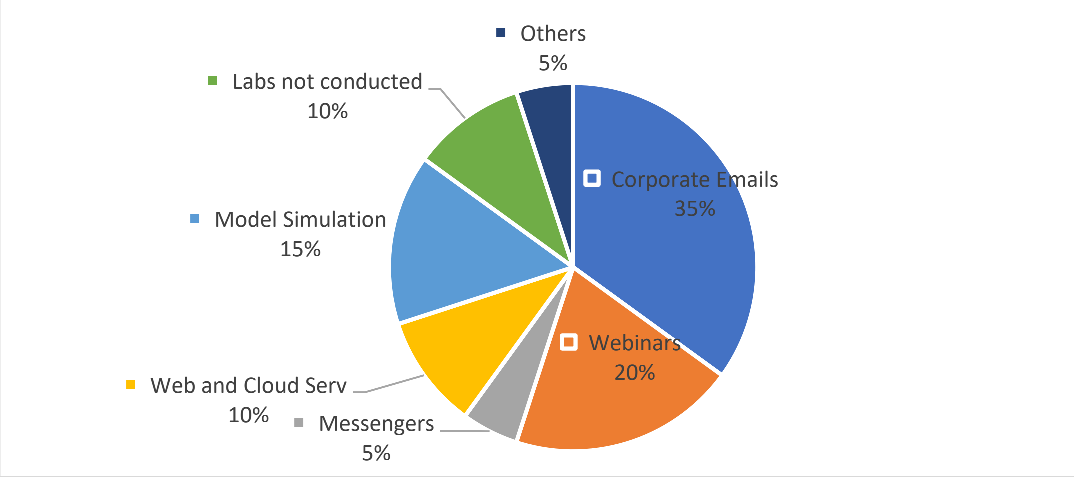

Fig 1. Use of various Technological Platforms for teaching of Engineering and Construction Management Courses.

4.2 ***Perceptions of students for Online Education of Urban Planning and Engineering courses:*** The sudden transition from purely face to face modes to online mode for teaching of design courses, certainly created many concerns amongst the students. Based on the post Spring 2020 semester review, it was revealed that almost 48.8% students regraded the online system as either good or very good. A big majority of students, declared it either satisfactory or poor (47.6%), whereas only 2.7% declared it, same as face to face education. The major impediments for effective online teaching of design courses, as identified by students are given in Fig 2. Students also reported psychological and social impacts of the lockdown, as they lost their contacts with the peers and project team members in face to face mode. In case of resurgence of COVID-19, beyond the Spring 2020 semester majority of the students (48%) preferred the face to face mode, whereas 32% opted for online education and 15% for hybrid learning. This shows reasonable acceptability of online and blended learning (combined 47%). Based on this analysis, the subsequent Fall 2020 semester was designed and implemented on hybrid/blended learning mode. ***iii. Teachers' Perceptions about Online system for teaching of design and Engineering Courses.***

The sudden transition to purely virtual platforms, created many challenges for faculty and teaching support staff as well. Majority of the teachers were though using the computerised design tools during face to face system, yet the online teaching and assessment still remained a major challenge for them. One of the major issues faced by almost all the faculty (81%) in teaching of design and Engineering courses was non availability of appropriate writing and sketching tools (digital pen) for online design work. The non-availability of personalized printer, scanner and plotter with the students and faculty was another major issue at their home places. Faculty also faced the technological issues such as non-availability of reliable high speed internet, professional webcam, licenced software for teaching and design exercises, non-availability of tablet etc. The major challenge was faced in the assessments, though a breadth of assessment tools were provided to the faculty by the Higher Education Commission and their institutes. The work study/teaching balance was another issue, as the teachers were required to develop their online lectures and record them for asynchronous teaching, which doubled their efforts. At the same time, their personal privacy and family lives were also compromised. In blended learning, when students were divided in 3-4 small cohorts, concerns were shared about the extensive teaching to the students. To address, this challenge the teaching was condensed to 75%, which again created quality challenges. These major challenges are given in Fig 3.

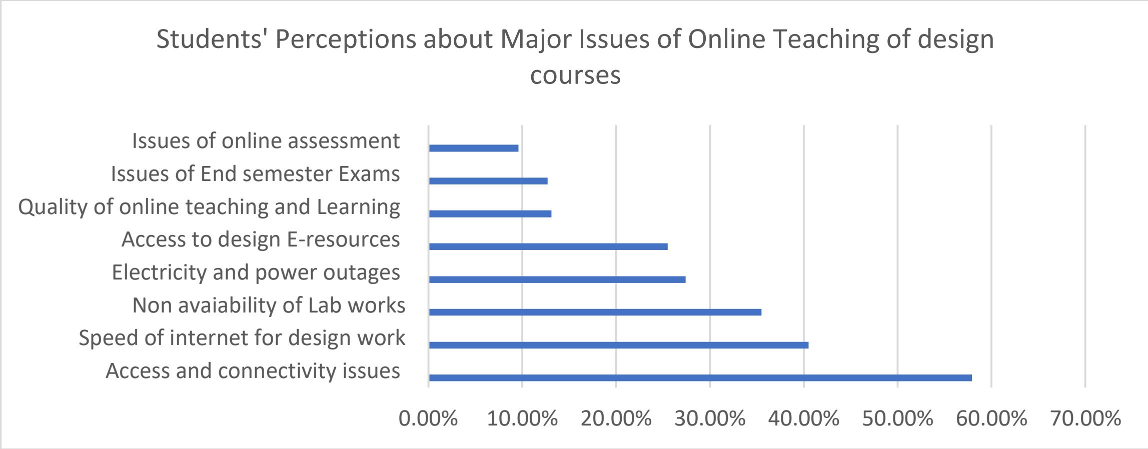

Fig 2. Students' Perceptions about the online teaching of Design Courses (n=175)

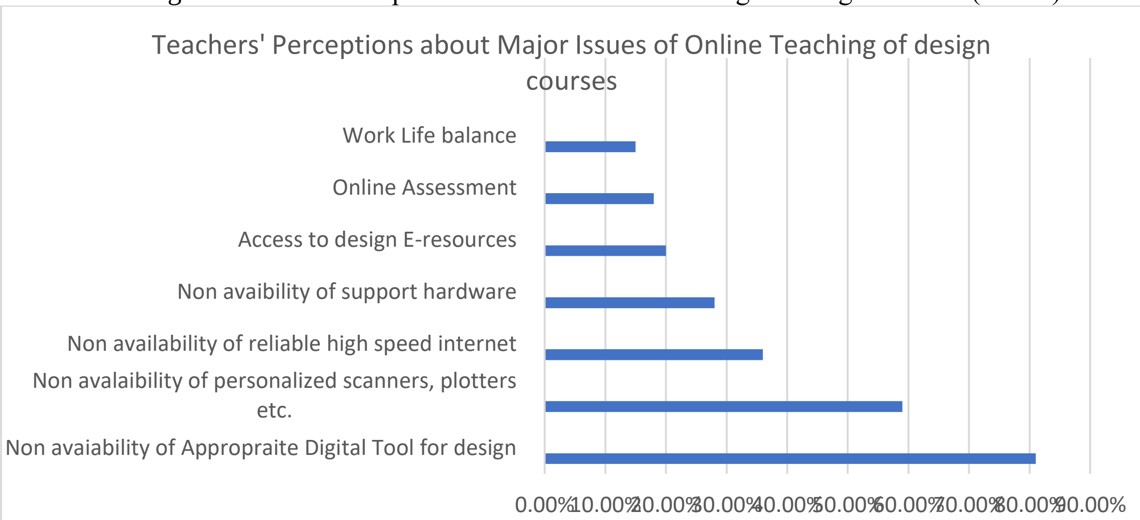

Fig 3. Major challenges for faculty of design schools during teaching and assessment of design courses in COVID-19.

iii. ***Logistic issues including hardware and software challenges***

Various technological teaching and learning provided ample free of cost courses for the benefit of students and faculty during COVID-19. The access to Open Educational Resources (OER), provided ample opportunities for students and faculty to learn from these resources. Yet the major challenges of appropriate teaching and assessment platform in terms of software and hardware was faced by all institutes. Faculty used various platform like Google meet®, Microsoft Team ® and Zoom ®, but all this software had their own limitation.s The availability of licensed software to students and faculty, online exams, online submission of assignments and time management remained major challenges.

iv. ***Limitations on design Labs during online teaching and learning:***

Based on the feedback from senior faculty and students, teaching of design lab work remained one of the major challenges. Design Teachers reported that a minimum of laptop of core i5 and window 2007 was required at the instructor's end for teaching of normal design Lab courses, however for high level courses, involving complex design solutions, Core i7 and latest version of Windows may be required. Besides licensed software, guidelines for online teaching of Lab work, its assessment, attendance mechanism, high speed internet with ample bandwidth and clear guidelines for assessment of design lab work will be required. The teaching of Design Lab will remain the major challenge, even if these supports are provided.

v. ***Guidelines of the Regulatory bodies for teaching and assessment of design and Engineering courses.***

Within the challenges of the online education and assessment for design and Engineering courses, the technology and design experts, still explored to innovate appropriate tools and processes to continue with the education during pandemics. Pakistan Engineering Council, the regulatory body for Engineering Education Town Planners (PCATP) for design and architecture education provided various guidelines in consultation with Higher Education Commission (HEC) of Pakistan. The important policy guidelines are reproduced as follows (PEC, 2020; PCATP, 2020).

- **Class size**: Online class was advised not to be greater than 100 for online engineering and design courses and 240 for non-engineering courses.
- **Content Delivery**: Faculty must be trained and assessed by a senior committee, with special reference to use of audio, video and sharing of screens and materials.
- **Attendance**: The Engineering and design schools, are responsible to introduce suitable monitoring & feedback evaluation mechanism to record/ log students' participation
- **Assessments and Quizzes**: Assessments, number of quizzes and type of assignments/PBLs/CEPs must be innovative enough to cover Course Learning Outcomes (CLOs) to attain respective Program Learning Outcome (PLOs) of the courses appropriately.
- **Final Year Design/Capstone Project (FYDP):** may be conducted by using computer-based simulation, presenting literature critiques or system designs etc. utilizing appropriate modern tool usage and technologies.

iv. ***Impact of COVID-19 on research activities in Engineering and design schools***

The ban on face to face interaction due to forced lockdowns for more than a year now, has seriously jeopardized the research interventions of the Engineering and design schools. The external evaluation of design works by juries and peers has restricted the inputs of the experts to the design reviews. Similarly, the research activities across the country and design schools in terms of face to face International and National Conferences, Workshops, Seminars, Colloquia etc. Nevertheless, the online platforms for teaching and learning provided ample opportunities for virtual research collaboration and virtual seminars and conferences have been increased manifold. These webinars, have replaced some of the isolation of students and faculty with involvement in the research activities. HEC, PEC and PCATP have provided guidelines for the external assessment of design work, final year projects and programs through virtual means.

iii. Conclusions and Recommendations:

The pandemic has certainly created serious issues for continuity of quality teaching and learning process for Engineering and Construction Management programs involving design interventions. Like other disciplines, various virtual portals have been used by the Engineering and design schools, yet the perceptions of the students and faculty remained varied. Majority of the students were not satisfied with the Lab work being offered through virtual platform. The major findings are summarised as follows:

i. Majority of the students, still support the Face to face teaching for effective teaching and learning process of Engineering and Design courses, especially the Lab design works.

ii. A number of issues have been identified by the students, impeding the effective teaching and learning process, which mainly include the poor access and connectivity to the internet, lack of availability of requisite technological gadgets for design work, issues with the assessments etc.

iii. The faculty at the other hand have also concerns about the virtual platforms which include non-availability of the requisite teaching tools, lack of capacity for online teaching and assessment, work life balance issues.

iv. The students and faculty has, even then supported to continue with virtual platform, blended with face to face teaching for limited time at the campus, so that they can manage their design & lab work on one hand and interact with their peers, teachers and class fellows to move out of the isolation.

Some of the major recommendations for effective teaching and learning of design and engineering courses are given as follows:

i. Substantial budgetary allocation required to both faculty and students for procurement of basic equipment for online teaching and learning of design courses. For access of faculty and students to reliable software and design tools, virtual desk top environment may be required.

ii. For strengthening of Lab work through virtual platforms, discussions, dialogues and problem solving activities may be encouraged.

iii. Repository of E-resources and recorded lectures may be provided to the students and faculty for asynchronous learning.

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Systematic Literature Review on Impact of Low slope vs. Steep Slope Roof Membrane Color on Energy Efficiency

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Abstract
A sustainable building envelope is important for building energy-efficient structures that contribute to sustainable communities. The current study compares the low slope versus steep slope roofing systems with varying solar reflectance and albedo factors to document the impact on energy efficiency via cooling/heating energy usage due to the roofing systems. A systematic literature review was conducted to compare the documented data from various literature sources with increasing solar reflectance and albedo scores and their impact on energy efficiency. The systematic literature review considered data from 65 papers to analyze parameters like solar reflectance and albedo for different types of roofs, identifying key limitations and gaps that pave the way for future study design on roofing systems. The study provides a useful tool to understand the impact of roof performance on energy efficiency and make informed decisions about implementing cool roofs.

Keywords
Cool Roof, Sustainability, Energy Efficiency, Albedo, Reflectance

1. Introduction
The United States of America has been ranked 41st out of 163 countries analyzed in the Sustainable Development Report 2022. This report highlights the importance of having a sustainable building envelope for sustainable cities and communities identified as an area of focus and improvement (Sustainable Development Report, 2022). The construction industry is the largest consumer of raw materials and produces waste material, which has negative impact on the environment. (UN Environment, 2017). For example, residential (steep-slope roofs) and commercial buildings (steep-slope and low-elope roofs) consume about 40% of the total energy usage in the USA. (Seiferlein et al., 2004)

The energy consumed during the operation and maintenance of buildings includes the energy needed for lighting, heating, cooling, and ventilation systems, as well as the energy consumed by electronic devices, appliances, and other equipment used in the building. Various strategies such as building insulation, efficient heating and cooling systems, and efficient building envelope such as use of efficient roof systems in building design can help reduce energy consumption. Roofs account for approximately 20%-25% of building surfaces in urban areas (Costanzo et al., 2016). Additionally, roof systems are critical to thermal performance of a building as it contributes up to 50% of the total thermal load of the building (Nahar et al., 2003). Some of the solutions include modifications on the roof's surface, such as changing the color or utilizing high reflective materials. (Boixo et al., 2012)

The current study looks back in time, collates the findings and analyzes the impact of changing albedo and solar reflectance on energy efficiency. The Solar Reflectance measures a roof's capacity to reflect solar energy back into the atmosphere (scale 0-100). Albedo is the proportion of incident radiation that is reflected from the surface of the roof (Dobos, 2005). The solar energy that is not reflected by the roof is absorbed, raising the temperature of the building. Albedo values vary from 0 to 1, with 0 being the darkest surface and 1 representing the lightest surface, absorbing 100% and 0% of solar radiation, respectively. The objective of the study is to conduct 1) a systematic literature review to document the effect of solar reflectance and albedo of roofing membrane on the energy efficiency of a building and 2) to organize the data and findings based on study design parameters to capture the changing efficiency over solar reflectance and albedo scores.

2. Methodology

This study examines the changing albedo and reflectance scores and its impact on energy efficiency for various roofing systems. SLR involves comprehensive search is conducted to identify relevant literature. This can include databases, journals, conference proceedings, and other sources. Further, this study synthesized and analyzed data collected from the literature and then summarized and organized into themes to facilitate the analysis. With various approaches to searching dedicated words and word associations in a literature review, such as narrative summary; content analysis; case, survey, and comparative analysis; this study identified literature with the defined keywords in the beginning and followed up with content and comparative analysis (Sharma et al., 2022). Various combinations of key words including, but not limited to 'cool roof', 'energy efficiency', 'albedo', 'reflectance' and 'insulation'. Table 1 shows the results of a search run on twelve (12) databases using a combination of the above-mentioned keywords.

Table 1: Search results and Database keywords

S. No.	Database	# of initial identification	# of inclusion criteria	Keywords
1	Engineering Village	178	12	
2	ProQuest	287	3	
3	ACM Digital Library	1	0	
4	Web of Science	234	7	
5	Business Source Complete	20	2	"cool roof" AND "energy efficiency" "cool roof" AND "temperature" "cool roof" AND "albedo" "cool roof" AND "reflectance" "cool roof" AND "insulation"
6	Academic Search Complete	97	10	
7	Berkeley Lab Heat Island Group	165	6	
8	Springer Link	172	2	
9	IEEE	32	1	
10	Wiley Online Library	71	2	
11	OSTI	121	5	
12	Clemson Libraries	313	15	
	Total	1691	65	

The keywords and their Boolean logic combinations (Yoshii et al., 2009) were searched for the initial identification of relevant publications across various databases (Sharma et al., 2022). This initial search retrieved 1,691 articles over the last 20 years. The inclusion criteria were (1) only peer-reviewed publications; (2) articles with data on various roofing systems and its impact on energy efficiency that measure cooling/heating energy usage, dollar savings, temperature reductions; (3) cases from all over the world; and (4) authenticity of the source. An overview of the process for selecting the relevant article is shown in Table 4.

Table 2: Selection of relevant articles

Steps	Results
Step 1	Initial identification based on keywords 1691 articles identified
Step 2	Narrowing down initial identification based on inclusion criteria, peer reviewed articles and study design 747 Articles selected
Step 3	Review of articles and abstract to identify articles relevant to the aims of this paper 325 Articles eligible
Step 4	Review of articles that quantify the effect of cool roof on energy efficiency 65 Articles included

The following factors were identified through an extensive literature review.

- Sample size of the roofs investigated, study location, climate, the color of the roof membrane (albedo and reflectance scores), low vs. steep slope, study limitations and conclusions.

The current scope includes, sample size of the roofs investigated for low vs. steep slope roofing systems. The goal of this stage is to identify patterns, trends, and relationships in the data, as well as to draw meaningful conclusions from the data. The data analysis process involves systematically reviewing the collected data, categorizing it in accordance with the established criteria, and identifying patterns and themes. In the end, the steering committee validated results.

3. Results and Discussion

The purpose of the systematic literature review was to analyze the impact of reflectance and albedo on energy efficiency of buildings. The review focused on the energy usage reduction that can be achieved through the implementation of cool roofs. To achieve this goal, the literature review assessed 65 different papers related to the subject matter. The review considered a wide range of research studies, including academic papers, technical reports, and other relevant publications. The literature review investigated the impact of reflectance and albedo for TPO, EPDM, PVC, built-up roofs, asphalt shingles, metal roofs, concrete roofs, and clay tiles, further categorized roof systems into low slope and steep slope roofs.

3.1 Data Sample

The studies investigated for energy efficiency of various roof systems provides a comprehensive understanding of the geographical footprint as it is a critical factor that influences the efficiency of the system. The studies were analyzed in different regions of the world, including the United States of America, Asia, Europe, Australia, Africa, and South America. The sample size and the geographical distribution of studies is shown in Table 3 and Figure 1.

These studies were mainly focused on evaluating the energy-saving potential of cool roofs against a standard roof in different climatic zones and building types prevalent in the region. The standard roof system is the one without any modifications, such as coating, membrane color, insulation thickness, etc. The studies investigated and highlighted the various approaches and perspectives adopted to improve building's energy efficiency in different regions of the world.

Table 3: Sample size, location and climate of data points

Type of Roof	Sample size	Location	Sample size	Climate
Low Slope Roof	221	USA	47	Temperate, Sub-tropical climate
		Asia	77	Temperate, Sub-tropical, Sub-equatorial climate
		Europe	63	Temperate, Sub-tropical climate
		Others	34	Tropical, Sub-tropical, Equatorial, Sub-equatorial climate
Steep Slope Roof	137	USA	62	Temperate, Sub-tropical climate
		Asia	15	Temperate, Sub-tropical, Sub-equatorial climate
		Europe	25	Temperate, Sub-tropical climate
		Others	35	Tropical, Sub-tropical, Equatorial, Sub-equatorial climate

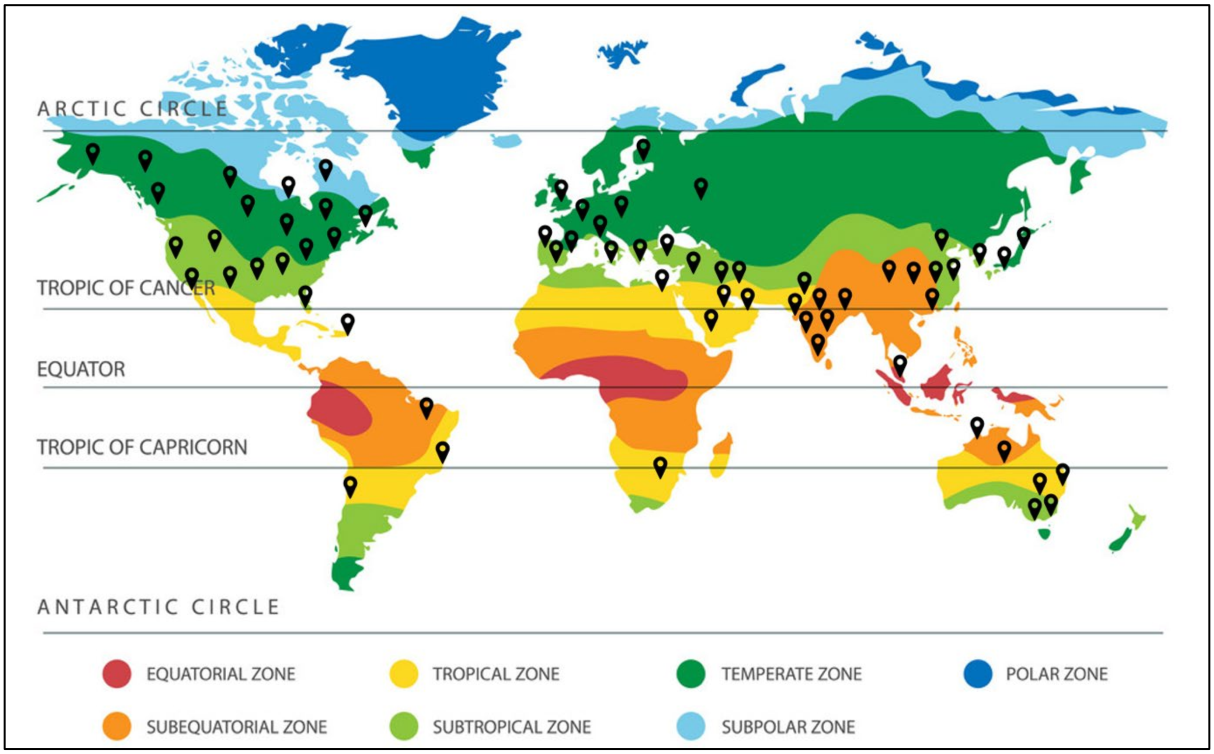

Fig. 1 – Geographical distribution of studies

3.2 Synthesis and Analysis of data

The graphs below show the effect of reflectance and albedo on energy efficiency of a building. Energy efficiency is defined as the percentage change in energy usage of a standard roof and a modified roof. The solar reflectance of a roof system is a product of the properties of the roof material and albedo is the lightness of a roof. Each of study shown in Figures 1, 2, and 3 are listed in the reference section.

Figure 2 shows the effect of reflectance on energy efficiency for low slope and steep slope roofs of all colors. For every change in reflectance by 10 units, there is an increase in energy efficiency by 4.5% for low slope roofs and 1.5% for steep slope roofs.

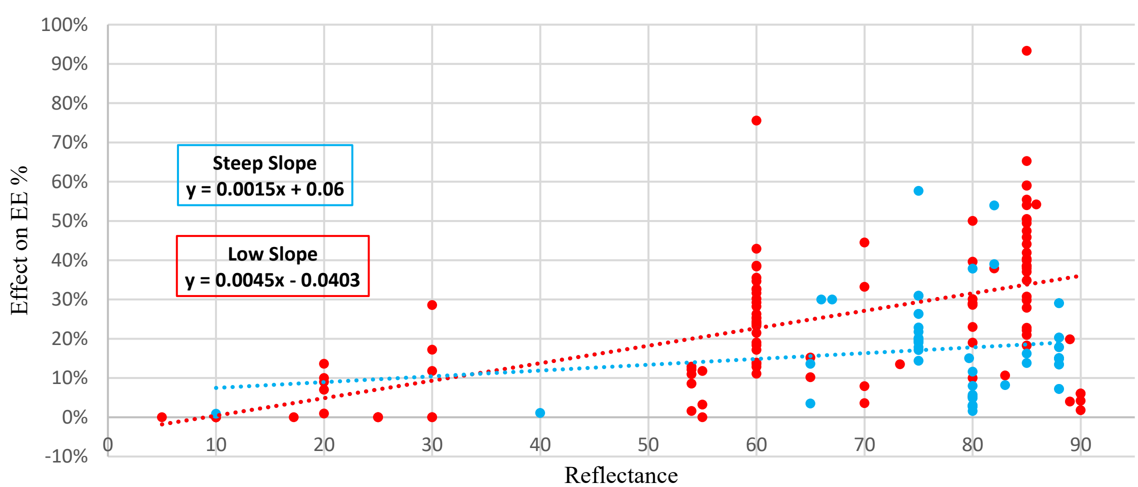

Fig. 2: Effect of Reflectance on Energy Efficiency

Low slope roofs have better performance with higher solar reflectance as it is a product of the material of the roof. Figure 3 shows the effect of albedo on energy efficiency for low slope and steep slope roofs of all colors. For every change in albedo by 0.1 units, there is an increase in energy efficiency by 2.2% for low slope roofs and 5.5% for steep slope roofs. Steep slope roofs have better performance with higher albedo as it is a product of the lightness of a roof membrane.

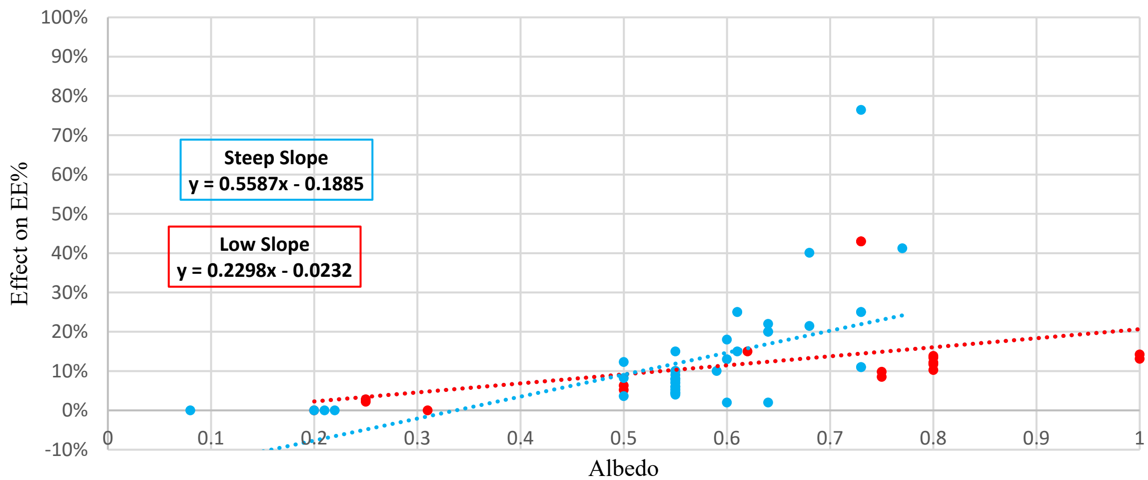

Fig. 3: Effect of Albedo on Energy Efficiency

Cool materials like liquid applied coatings or single ply membranes that have high reflectance result in surface temperature reductions ranging from 5 to 13 °C when compared to their equivalent conventional colors. (Levinson et al., 2007, Loh et al., 2010) A literature review study found that cooling energy savings range from 2% to 44% in residential and commercial buildings, with an average of around 20%. According to the literature, cool roofs can save between 3% and 35% on cooling energy, depending on ceiling insulation levels, duct placement, and attic structure. These findings, however, are only applicable to conventional US structures. (Haberl et al., 2004)

The existing research on the effect of installing a cool roof has been limited to isolated individual studies conducted in various parts of the world. Multiple studies have focused on data from certain months, which prevents the assessment of the roof's annual performance. There needs to be future studies that better document the impact of multiple variables changing simultaneously or identify them as limitations.

Moreover, the thermal insulation thickness plays a key role in reducing heat gains in hotter climates and minimizing heat energy loss in colder climates that also needs to be considered. In addition, the impact of insulation on energy efficiency needs to be modeled as against the impact of lightness of the roof. Additionally, the energy efficiency of a cool roof is often evaluated based on the cost savings achieved in different locations without normalizing the cost of electricity. It is essential to compare the cost savings as electricity cost can vary greatly from one location to another. Thus, in order to accurately evaluate the energy efficiency of a cool roof, it is important to consider multiple factors such as insulation thickness, cost of electricity, and the effect of multiple variables changing simultaneously and yet focus on comparing roofs in similar climate zones.

This systematic literature review aims to fill the gap in the current body of knowledge on the effectiveness of cool roofs in different climate zones. Due to the growing popularity of cool roofs and their potential benefits, it is critical to design a comprehensive study considering the impact of reflectance, albedo, and insulation on annual energy consumption along with envelope characteristics.

The primary goal of this study is to provide a comprehensive analysis of the roofing industry, consolidating the findings of multiple earlier studies to provide a true comparison between a standard roof and a cool roof. This study took various factors into consideration that affect roof performance and their impact on energy efficiency and realized the roofing industry needs a comprehensive study on cool roofs, their benefits, and challenges to keep up with recent advancements in the field. The value of this work lies in its ability to bring together the existing knowledge and provide a consolidated understanding of the effectiveness of cool roofs in different climate zones.

4. Conclusions

The paper evaluated various studies and their findings on the effect of cool roof on energy efficiency of low slope and steep slope roofs. Evaluating the energy efficiency of a building requires consideration of various factors, including solar reflectance, albedo and baseline energy usage values. The studies were analyzed in different regions of the world and the results show that with an increase in reflectance and albedo, the effect on energy efficiency increases. The baseline value of energy usage is an essential factor in determining the percentage of savings and energy consumption reduction. A lower baseline value shows a higher percentage of savings, but less energy consumption reduction than a higher baseline value. For e.g., in temperate and cold climates with a lower baseline case of energy usage, there are more percentage savings but less energy consumption reduction. As a result, future studies that focus on the impact of the changing climate, especially in temperate and cold climates on energy efficiency with various roof modifications (color, product type, insulation, etc.) are needed. Similarly, a study on life-cycle analysis to calculate the energy savings in terms of dollar value over the life of a roof with an emphasis on the cost-benefit analysis identifying effective roofing materials and designs is needed.

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Key Contributors to Delays on Road Construction Projects in South Africa

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Abstract
Delays in road construction projects in South Africa are a common phenomenon. This research examined major contributors to delays on road construction projects. Limited research has been undertaken in South Africa, and the South African National Roads Agency, Limited (SANRAL) commissioned projects. The study used a quantitative research approach that employs a structured questionnaire administered to clients, consultants, contractors and stakeholders involved in SANRAL projects. At the end of the survey period, 64 responses were received, and the data collected were analysed using descriptive and inferential statistics. The study found that the primary cause of delay in road construction projects are: unrest/protest by local communities and the stoppage of work by construction mafia/neighbouring communities/wards. It also emerged that key effects of delays are: cost overruns, disputes and claims between contract parties. The study further found that the top delay minimising measures include: early engagement and improved communication with the community and timeous payment to contractors and consultants. The study concludes that the major contributor to delays on road construction projects are external-related and recommends the early involvement of the community stakeholders at the project inception stage through community liaison meetings and the establishment of a Public Liaison Committee (PLC).

Keywords
Community participation, Cost overrun, SANRAL, Stakeholder Management, Time overrun

1. Introduction

According to Tsikai (2016), transport plays a major role in the the economic growth of a country. When a country's transport system is efficient, it results in economic and social opportunities and benefits that have positive effects such as better accessibility to markets, employment, and additional investments in the country (Rodrigue and Notteboom, 2020). On the contrary, when the transport system is deficient, it results in economic cost, reduced opportunities, and a lower quality of life (Rodrigue and Notteboom, 2020). The economic development of South Africa depends on reliable and sustainable road infrastructure to allow for the transportation of the country's produce from inland to the ports for export, commuting to work, shopping and tourism.

The South African government is focused on job creation through infrastructure development, and this is supported by the government's intention to unlock R1 trillion in infrastructure projects over the next couple of years (South African Government, 2020). At the 2020 State of the Nation Address, President Ramaphosa called on both public and private sectors to invest in infrastructure development projects that will stimulate the country's economy. This was followed by the transport minister's commitment to use road infrastructure development as a key contributor to job creation. The government aims to create more than 60 000 jobs for labour intensive maintenance and construction of municipal infrastructure and road projects (Nkgweng, 2020).

The word delay in the construction industry refers to a specified task not occurring as planned in the construction programme (Pickavance, 2005), the late completion of work as opposed to the agreed contract schedule (Vijekar and Ugle, 2015), actual completed construction work is slower than the planned schedule (Hamzah et al., 2011). Construction delays are categorised into four types: non-excusable delays, excusable non-compensable delays, excusable compensable delays, and concurrent delays (Kikwasi, 2012). Project delays in the road construction industry are becoming more common in South Africa with SANRAL reporting a significant increase in construction delays on several major projects in the 2018/19 financial year (SANRAL, 2019). Multiple studies including Kaliba et al. (2009) and Aziz and Abdel-Hakam (2016) view project delays as a major problem in the construction industry globally. Contractors are noted to have voiced their concerns over the difficulty in overcoming construction delays due to their inability to identify the main reasons for the delays (Aziz and Abdel-Hakam, 2016).

Although studies like those of Sambasivan and Soon (2007), Kamanga and Steyn (2013), and Divya and Ramya (2015), amongst other studies, have been conducted in different parts of the world on this subject, limited research has been conducted on the causes of delays in road construction projects in South Africa and its unique environment. Because of the uniqueness of each project and its environment, the causes of delays may vary from region to region and country to country. There is also limited knowledge of project delays in South Africa and SANRAL commissioned projects, and current literature does not address the issues discussed above. Furthermore, there is limited information on external and internal factors causing delays, and which is the most significant contributor to construction project delays in South Africa. In addition, while most studies focus on delays during the construction phase, few studies have analysed delays during the planning and design phase (Halim and Zin, 2016; Yang and Wei, 2010). The limited research on delays during the planning and design phase and whether internal more than external factors is responsible for the delays creates a gap in the current literature on delays in road construction that are addressed in this study.

This research examines the main causes and effects of delays on South African road construction projects from the view of SANRAL Project managers, consultants, contractors, and others involved in the project, in order to determine whether external-related causes of delays are more significant contributors to construction project delays in South Africa. This study will assist policymakers such as SANRAL and the Department of Transport (DOT) in formulating appropriate strategies that address and reduce road construction delays that can be adopted at a national level.

2. Overview of the Transport Sector in South Africa, Construction Project Delays and Causes of Delays in Construction Projects

2.1 Overview of the Transport Sector in South Africa

South Africa has a road network 750 000km long, the longest in Africa and tenth longest in the world (DOT, Republic of South Africa, 2020). The South African government is the sole client for road construction projects while the DOT is responsible for the legislation and policies for rail, air, sea, road and pipelines in the country. SANRAL is a crucial state-owned entity that is responsible for the upgrading, maintenance and strengthening of national roads in the country, approximately 21 403kms long. The provincial departments of transport are responsible for approximately 47 348 km of road whereas 51 682km is managed by municipalities.

2.2 Causes of Delays in Construction Projects

Construction delay is described as the untimely completion of construction work, or the project compared to the agreed contract schedule (Vijekar and Ugle, 2015). Several authors such as Bagues et al. (2020); Divya and Ramya, (2015); and Enhassi et al. (2006) have researched the causes of delays in construction projects with some research attempting to categorise the causes of delays based on the responsible stakeholder or project components such as labour, financial, material and equipment. Other notable studies on delays on construction projects were undertaken by Bekr (2018), Mashwama et al. (2018) in South Africa, Motaleb and Kishk (2010) in the UAE, Fugar and Agyakwah (2010) in Ghana, Odeh and Battaineh (2002), Muhwezi et al. (2014) in Uganda, Assaf and Al-Hejji (2006) in Saudi Arabia and Sambasivan and Soon (2007) in Malaysia. Although there are similarities in the findings of these studies, there are some geographical limitations which limit the application as a one solution finding in South Africa (Twana, 2015).

Delays on road construction projects in South Africa have been attributed to the project stakeholders. The Preferential Procurement Regulation framework prescribed by National Treasury on 01 April 2017 specifies that 30% of government projects must be sub-contracted to SMMEs to allow for job creation and skill development within local communities. This gave rise to the introduction of a "construction mafia" into the industry (Cokayne, 2018), where agents of radical economic transformation see the construction industry as an opportunity to gain economic benefit through violent disruptions (Donnell, 2019). This has affected the construction sector at a time where major contractors are filing for business rescue. More than 60 SANRAL projects were affected by disruptions by armed gangs demanding a stake of at least 30% in the project in the 2018/19 financial year (Donnell, 2019). This accounts for almost a quarter of the agency's projects.

In the study by Mashwama et al. (2018) in Gauteng Province of South Africa, the authors concluded that community unrest was the highest ranked factor that was of major concern to all project stakeholders (client, consultant, and contractor). The authors argue that the biggest threat to road construction projects is the delay due to the time spent in negotiations addressing community grievances and sometimes the unsettlement of issues that result in total abandonment of the project (Mashwama et al., 2018). Delays caused by communities included strikes, stoppages by business forums, interference by the construction mafia and councillors' interruptions (Mashwama et al., 2018).

For the purpose of this study, the delay causes were categorised into four categories: Client-related, Consultant-related, Contractor-related and External-related. These broad categories are similar to the ones adopted by previous authors (Amoatey and Ankrah, 2017; Bekr, 2018; Kaliba et al., 2009 and Muhwezi et al., 2014). Through a review of the available literature on the subject matter, the major causes and categories of delays were identified and summarised It should be noted that the literature surveyed is not limited to road construction only, but the construction industry in general.

Figure 1 proposes that the client, consultant, contractor and external-related factors cause delays on construction projects. Furthermore, the delays lead to budget and schedule overrun, legal issues and negative social implications. The study will examine whether external-related causes of delays are more significant contributors to construction project delays in South Africa. The research hypothesis is given as:

H_1: *External-related causes of delays are more significant contributors to construction project delays in South Africa than client, consultant, and contractor related causes.*

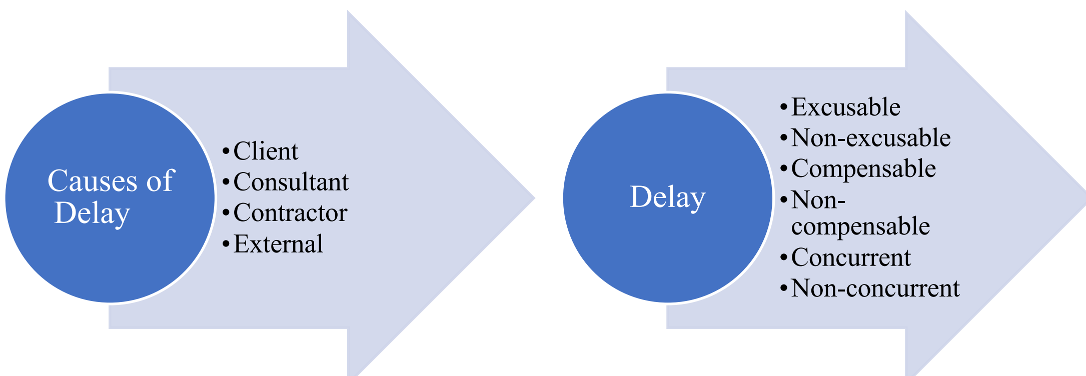

Fig. 1. Conceptual Framework of the Study

3. Research Methodology

This study adopted a quantitative research approach based on deductive reasoning because of the objective of the paper to determine the key causes of delay and to know the significant contributors to project delays which can only be undertaken quantitatively. The study is undertaken on SANRAL projects in South Africa. SANRAL is a state-owned entity with four regional offices, the organisation completes projects in all nine provinces in South Africa; therefore, information received from respondents who worked on projects will provide a holistic view of the causes of road construction delays in South Africa. The population of this study comprises project stakeholders including SANRAL project managers (clients), consultants, contractors and other external stakeholders who have worked on a SANRAL project. This study adopted a random sampling technique to allow for an equal chance of selecting all project stakeholders who worked on SANRAL projects. The number of stakeholders emailed per stakeholder group, number of responses per group received and response rate is shown in Table 1.

Table 1. Number of Questionnaires distributed and response rate per stakeholder category

Category of Stakeholder	Study Population	Completed Responses	Percentage Response
Client	40	21	53%
Consultant	34	24	71%
Contractor	22	13	59%
Other (public liaison officers)	10	6	60%
Total	106	64	60%

At the end of the survey period, a total of 64 responses were received from the 106 identified participants, representing a 60% response rate. This is above the minimum sample size of 30 proposed by Louanglath (2017) and adheres to the central limit theorem.

Section A of the questionnaire aimed at collecting the background information of the respondents, while Section B aimed at collecting project information and Section C obtained information on the causes of road construction delays. The questionnaire was set up using Microsoft Forms and a Likert scale was used to measure the degree to which the respondents ranked each of the causes of delays. The data collected from the questionnaire survey was cleaned to remove any errors (half completed questionnaire) to ensure accuracy of data being analysed. Data analysis methods used were the Relative Importance Index to determine the ranking of the causes of construction delays. Statistical software IBM SPSS Statistics 27 computer software in tandem with Microsoft Excel were used to analyse the data. The Kruskal-Wallis test was used in finding out whether there are significant differences in the perception of respondents when differentiated by their designation, while the Chi-square was used in testing the research hypothesis that: *External-related causes of delays are more significant contributors to construction project delays in South Africa than client, consultant, and contractor related causes.*

The quality of research is achieved through the measurement of the validity and reliability of the study. To improve on the quality of the questionnaire and to ensure that the identified causes of delays are relevant to the South African road construction industry, the questionnaire was reviewed by an expert and four senior construction managers working for SANRAL, representing SANRAL's four regions who were not part of the respondents. Cronbach's Alpha was used to measure the reliability of the data obtained. It is common in scientific research to consider an alpha value of 0.70 as a sufficient measure of reliability of an instrument (Taber, 2018). The results of the Cronbach's Alpha are presented in Table 2.

Table 2. Results of Cronbach's Alpha Showing Reliability of Survey Items

No.	Category of Results	Cronbach's Alpha
1	Client related causes of delays	0.827
2	Consultant related causes of delays	0.928
3	Contractor related causes of delays	0.924
4	External related causes of delays	0.843

Table 2 show Cronbach's Alpha values all above 0.7 with a minimum alpha value of 0.827. This shows the consistency of the results and the accuracy of the instrument in producing the same results.

The research adhered to the following ethical considerations: Respondents were assured of confidentiality throughout the research. Respondents were anonymised and not induced to participate in the study. The aim and objective of the study were clearly explained to all participants. The researchers ensured that the sample size was a true representation of stakeholders working on road projects in SANRAL and did not favour one stakeholder over another to create bias. The research acknowledged the work of previous studies by using citations and referencing where applicable.

4. Data Presentation, Analysis and Discussion

The results of the analysis of the background profile of the respondents, gender and age, professional experience and project information - location of the project, type, budget and if any delays occurred, and causes of delay is presented below.

4. 1 Background profile of the study respondents and identified projects

The results show that 70% of the respondents are male, while 30% are female. The distribution of respondents by age indicates an even distribution of respondents within three of the age groups, 36-40 years, 41-45 years, and 46-50 years all having (12.50%) respondents each. Furthermore, 38% of the respondents are in the Consultant group - design consultants, contract engineers and resident engineers; while 33% of the responses were from the Client group (SANRAL) – project managers, community development specialists, a project leader; followed by 20% from the Contractor group – contract and construction managers and project leaders; and 9% from the 'Other' (public liaison officers) group.

The analysis of years of respondents' experience and number of projects completed in the last five years reveal that 54.70% of respondents have over ten years of relevant experience, while 45.30% have less than ten years' experience in the road construction industry. While in terms of the number of projects respondents were involved in, in the last five years, the analysis revealed that 23.44% of the respondents completed more than ten projects, followed by 17.19% who completed two projects in the last five years, while 14.06% of respondents completed three, four and five projects within the last five years.

The type of project provides an understanding of the project's budget and the complexity associated with the project. Analysis of the projects identified by the respondents showed that new works, upgrades and strengthening projects consisted of the highest number of submissions (63.49%), followed by Routine Road Maintenance projects (14.29%). The remainder of the projects submitted were, operational maintenance (7,94%), special maintenance (6.35%), periodic maintenance (4.76%) and community development (3.17%).

The study sought to know whether the identified project experienced delays in the design phase and the construction phase. The results for percentage delays during the design phase and construction phase reveal an almost equal split between projects experiencing delays during the design phase with 48% of respondents indicating delays occurred and 52% indicating delays did not occur during the design phase. The same is not true for projects during the construction phase, with 90% of respondents indicating delays did occur and 10% indicating that delays did not occur. The above results indicate that delays are more frequent during the construction phase of projects in road projects in South Africa. The causes of the delays will be analysed and discussed subsequently.

4.2 Analysis of the causes of delay

A total of 47 causes of delays were identified through the literature review (see Table 1) and expert review of the pilot questionnaire. The causes of delays were categorised into four major groups: Client-related, Consultant-related, Contractor-related and External-related causes. The causes for each group were analysed statistically and ranked using their relative importance index (RII).

The results of client related causes of delays reveal that from a ranking perspective, the respondents perceive that the five major client related causes of delay are delays due to regulatory approval processes, delay in decision making by the client, delay in reviewing and approving drawings and documentation, changes in design and changes in project scope. The results of the consultant related causes of delays reveal that from a ranking perspective, the respondents ranked errors in the contract documentation, poor communication between client and contractor, unclear and inadequate details in construction drawings, inadequate experience/skills of consultants and changes in design during construction.

The contractor related causes of delays analysis show that from a ranking perspective, the respondents ranked poor management of sub-contractors, employee strikes, late payment to subcontractors, poor management and supervision by contractors and cash flow difficulties as the major causes of contractor related construction delays. The external related causes of delay revealed that the top five causes of delays are unrest by local communities, stoppages of work by construction mafia/neighbouring communities/wards, poor engagement with the local community, lack of acceptance of the project by the community and land acquisition delays.

To get a holistic view of the most important causes of delays in SANRAL road construction projects, all causes of delays were analysed together and the top five causes of delays are presented in Table 3. It can be seen from Table 3, that from a ranking perspective of the 47 identified causes of delay, the external related causes of delays account for a significant 80% of the top five causes of delays. Only one of the top five identified causes of delays are client related with no consultant and contractor related causes of delays in the top five causes. The number one ranked overall delay is unrest by the local communities followed by stoppages of work by construction mafia/ neighbouring communities and wards. The delay due to regulatory approval by the client is ranked third. The external delays due to poor engagement with local community and lack of acceptance of the project by the community are ranked fourth and fifth respectively.

Table 3. Top five overall cause of delays in SANRAL road construction projects.

Ranking	Cause of Delay	Category of delay	RII
1	Unrest by local communities	External	0.8406
2	Stoppages of work by construction mafia/ neighbouring communities/ wards	External	0.8063
3	Delays due to regulatory approval processes	Client	0.7719
4	Poor engagement with local community	External	0.7625
5	Lack of acceptance of project by community	External	0.7563

4.3 Kruskal-Wallis Test of differences in perspectives of respondents based on designation

The Kruskal-Wallis test results are presented in Table 4. The test was carried out at the 5% confidence level.

Table 4. Kruskal-Wallis Test Statistics for Causes of Road Construction Project Delays

Top Five Major Causes of Delays	
Kruskal- Wallis H	.679
Df	3
Asymp. Sig.	.878

Grouping Variable: All Project Stakeholders

The Kruskal-Wallis test shown in Table 4 reveals that there is no statistically significant difference in the respondents perception of the causes of road construction project delays when differentiated by their designation ($X^2(3) = 0.679$, $p = 0.878$). The calculated Kruskal-Wallis H value of 0.679 is lower than the critical value of 7.815 for three degrees of freedom and the calculated p-value of 0.878 is greater than the significance level of 0.05. Therefore, it can be inferred that there is no significant difference in the perception of the respondents on the causes of delays on construction projects when differentiated by their designation.

4.4 Chi-square test of the category related cause of delays on construction projects

The Chi-square test results of the Chi- square tests are presented in Table 6.

Table 5. Testing for Hypothesis using Chi-square Test

Cause of Delay	Client-related	Consultant-related	Contractor-related	External-related
Chi-square	31.94	34.28	48.03	54.13
Critical Chi-square	9.488	9.488	9.488	9.488

The calculated Chi-square values for all categories of causes of road construction delays on SANRAL projects presented in Table 6 are greater than the critical Chi-square value at 4 degrees of freedom and 5% level of confidence. Since the calculated Chi-square for external-related causes of 54.13 is greater than the client-related (31.94), consultant-related (34.28) and contractor related (48.03) groups, and it is greater than the critical value of 9.488 at 4 degrees of freedom and 5% level of confidence, the null hypothesis is rejected, and the alternative hypothesis is accepted. It can therefore be inferred from the Chi-square test that external causes of delays are more significant contributors to SANRAL construction delays in South Africa than client, consultant and contractor related causes.

4.5 Discussion of Findings

There are many causes of delays in road construction projects as indicated in previous studies (Divya and Ramya, 2015; Kamanga and Steyn, 2013; and Sambasivan and Soon, 2007), and studies such as those of Twana (2015) indicated the geographical isolation of these delays. The causes of delays are discussed according to the client related, consultant related, contractor related, and external related causes. An overall view of the top five major causes of delays in road construction projects in South Africa is also presented and discussed. Moreover, the Kruskal-Wallis Test has revealed that there is no statistically significant difference in the perception of top five major causes of road construction project amongst the project stakeholders.

Client related causes of delays

The delay due to regulatory approval, ranked first as a client related delay was identified after the pilot review of the questionnaire by experts in the industry. The main factor contributing to this cause is the delay in finalising the tender proforma document. SANRAL is a state-owned entity that awards work through the tender process. Each element of the project whether design, construction, environmental, health and safety or drilling gets awarded via tender. Without a proforma tender document, the work cannot be awarded, and progression of work is affected resulting in the project experiencing delays. This is further supported by the comments of one respondent who stated "delay in procurement" under the reason of other causes of delays not listed in the questionnaire, not identified in the literature review or identified through the pilot testing of the questionnaire. Delays ranked second and third are closely related and involve the decision making by the client. This is aligned to previous research by Assaf and Al-Hejji (2006) who found that clients' delays in decision making is a major cause of construction delays.

Consultant related causes of delay

The following are the consultant related causes of delay from a ranking perspective: errors in the contract documents, poor communication by the consultant between the client and contractor, unclear and inadequate details in construction drawings and inadequate experience and skills of the consultant were both ranked third, while delay due to changes in design during construction drawings was ranked the fifth. This is in total agreement with Bekr (2018), who also ranked errors in design and contract documentation as the most influencing delay causing factors that are consultant related.

Contractor related causes of delay

Poor management of subcontractors was ranked first for contractor related causes of delays followed by employee strikes, late payment to subcontractors, poor management and supervision by contractor and cash flow difficulties. The top five causes of contractor related delays can be grouped into two themes, which are management and supervision and financial difficulties. The delay due to poor management of subcontractors (ranked first) is supported by the study by Bekr (2018). In South Africa, subcontractors are listed in Grade 1 to Grade 6 CE, and have very little knowledge in the construction industry. They are start-up construction firms looking to join the industry. Poor management of these subcontractors will result in construction project delays as seen in the results in this study.

External related causes of delay

The top five external related causes of delays listed in order of rank include unrest by local communities, stoppages of work by construction mafia/neighbouring communities/wards, poor engagement with local community, lack of acceptance of the project by the community and land acquisition delays. The central cause of external related delays from the analysis is due to community issues. The delays arise from the time spent in negotiations with the community addressing their grievances. These finding is consistent with finding of previous research by Mashwama et al. (2018) who based on a study undertaken in South Africa identified community unrest and the activities of the local community as major factors that resulted in projects experiencing delays respectively. The results due to stoppage of works support earlier studies by Oshungade and Kruger (2017) who found that when the community are not benefiting from employment on a construction project, they stop the work, resulting in project delays until grievances are addressed.

5. Conclusions and Recommendations

The study sought to find out the major causes of delay on road projects and whether external-related causes of delays are more significant contributors to construction project delays in South Africa than client, consultant, and contractor related causes. Forty two causes of delays emerged from the review of relevant literature about causes of construction delays and five were suggested by experts during the review of the pilot questionnaire resulting in a total of 47 causes of delays used in the study categorised into four major groups: client-related, consultant-related, contractor-related, and external-related causes of delay. The results showed that four of the five overall causes of delays in SANRAL road construction projects in South Africa from a ranking perspective are: unrest by local communities; stoppages of work by construction mafia/neighbouring communities/ wards; delays due to regulatory approval processes; poor engagement with local community; and lack of project acceptance by the community. The study found no statistically significant difference between the views of stakeholders on the causes of delay on road construction projects. Furthermore the test of the hypothesis showed that external-related causes of delays are more significant contributors to construction project delays in South Africa than Client, Consultant, and Contractor related causes. Based on these findings, the study concludes that a focus on addressing the external related causes of delays that involves communities will help minimise delays on road construction projects.

The study therefore recommends that the community should be involved early in the project through the establishment of community liaison meetings and the establishment of a Public Liaison Committee (PLC). Any concerns of the community should be addressed through the PLC without disrupting the project's schedule. SANRAL should improve its administrative processes towards improving the time it takes to make a decision with regard to the proformas and tendering criteria. Furthermore, clients should ensure timeous payments to consultants and contractors for completed work. This will assist contractors with cash flow, allow them to pay site staff and subcontractors on time and reduce the identified delays of employee strikes and late payment to subcontractors. It will also assist contractors in the payment for materials and for the servicing and maintenance of their equipment. Future research that examines the involvement of the local community in the planning of road construction projects in South Africa is also recommended.

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Impact of the Covid-19 Pandemic on the adoption of E-Procurement in the South African Construction Industry

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Abstract
The uptake of e-procurement in the South African construction industry (SACI) has been generally slow. The onset of the Covid-19 pandemic presented an opportunity for this to change due to the new ways of working that had to be adopted. The paper examines the drivers of adopting e-procurement in the SACI post the Covid-19 pandemic towards understanding the advances made by the industry in the wake of the pandemic. A literature review of the drivers of e-procurement was undertaken to develop a framework to guide the study. The study used a quantitative research approach employing a cross-sectional research design survey of respondents working for companies listed on the Construction Industry Development Board (cidb) Register of Contractors in data collection. The study utilizes descriptive statistics in determining the critical drivers of adopting e-procurement on construction projects before and after the Covid-19 pandemic. Despite previous studies indicating that e-procurement rates increased post-Covid-19, the study found that the pandemic does not significantly influence the adoption of e-procurement on projects in the SACI. It was also found that the key drivers responsible for adopting e-procurement on construction projects are 'improved flexibility' and 'improved response time of the procurement process', and 'reduction of paperwork within the contracting or client company'. Based on the findings, the study recommends increased flexibility of the procurement process to allow for adopting electronic means of procurement towards improving the competitiveness of the SACI and its currency.

Keywords
Competition, Covid-19, Digital procurement, Procurement, South African Construction Industry

1. Introduction

The early stages of procurement were based on traditional procurement, which was paper-based. Procurement adopted electronic systems such as Enterprise Resource Planning (ERP) to support it (UN, 2006). Electronic procurement, or e-procurement or supplier exchange, is the procurement of goods, services, and works through information technologies - such as ERP and Electronic Data Interchange (EDI) - that rely on the internet (Farzin & Nezhad, 2010, p.1). E-procurement includes e-tendering, e-catalogue, and e-payment; e-MRO, web-based ERP, e-sourcing, e-reverse auctioning and e-informing to the list of EP tools (Tran, Nguyen & Nazir, 2016).

Generally, the uptake of e-procurement has been slow. The percentage adoption rate of e-procurement in the SACI has been documented as being as low as 11% (Ibem & Laryea, 2015) - far lower than in other developing countries. The onset of the Covid-19 pandemic presented an opportunity for this to change due to the new ways of working that had to be adopted. As a result of the Covid-19 pandemic, a nationwide lockdown was enforced in SA, which meant that many people were restricted to their homes and places of work- excluding those deemed essential - could not operate during lockdown level 5 (Disaster Management Act no.57 of 2002, as amended, 2020). Additionally, people who were infected, or were in contact with those who had been infected, had to self-isolate. Olatunji et al. (2021) noted that the remote working required during the post Covid-19 period provides an opportune environment to support e-procurement adoption.

There are limited studies focused on the drivers of the adoption of e-procurement in the SACI. It is not known whether the onset of the Covid-19 pandemic and its resultant restrictions and lockdowns in SA necessitating remote work and telework in different industries' work practices- including the construction industry would drive the increased adoption of e-procurement in the SACI. Therefore, this research examines the drivers for adopting e-procurement and e-collaboration within the SACI and whether Covid-19 served as a driver to increased adoption of e-procurement in the SACI. The research hypothesizes that Covid-19 significantly influenced the adoption of e-procurement in the SACI.

The following sections provide an overview of the adoption of e-procurement in the construction industry and the drivers of its adoption. The research approach and methods used in data collection and analysis are outlined, followed by the presentation of the results, conclusion, and recommendations.

2. Overview of the level of adoption, drivers to the adoption of e-procurement in the construction industry

2. 1 Adoption of e-procurement in the construction industry

E-procurement adoption in the Construction industry has historically lagged behind other industries, which has been attributed to the sector's conservative nature when adopting new technology (Laryea & Ibem, 2014). Industries like ICT have a 70% adoption rate; the Electronic sector of the Manufacturing industry has an adoption rate of 52% for e-procurement (Batenberg, 2007). In developed countries, rates of e-procurement adoption are as high as 61.7% in Singapore (Teo, Lin & Lai, 2009); 48% among SMEs on the South coast of Massachusetts, USA (Gunasekaran et al., 2009). In a developing country like Nigeria, the use of e-procurement among construction stakeholders was reported as being as high as 69.5 % (Ibem et al., 2021).

A 2014 study reported that only 11% of SA construction professionals had used e-procurement (Ibem & Laryea, 2015). This compares unfavourably with available records of both the developing and developed countries. However, it is worth highlighting that since the figures on SA were captured in 2014, there could have been an increase in subsequent years. This is illustrated by how Nigerian respondents who used e-procurement for 1-5 years formed the most significant percentage of overall users in the study by Afolabi et al. (2019).

2. 2 Covid-19 and its Effect on digital transformation in the Construction Industry

Previous studies (Kudyba, 2020; Bikse et al., 2021; Rehman, Shafiq & Afzal, 2021) show that the onset of the Covid-19 pandemic accelerated the adoption of digital transformation, which had been going on for years but at a slow pace. In some countries, the Covid-19 pandemic acted as a driver of the adoption of digital technology. Researchers found that Covid-19 acted as a driver for the adoption of digital tools and processes such as BIM, cloud-based collaboration and virtual project management in the United Arab Emirates Construction industry (Rehman, Shafiq & Afzal, 2021) and digital solutions in Latvia, which grew by 10% between May to July 2020 compared to the previous year (Bikse et al., 2021). In contrast, Ebekozien and Aigbavboa (2021) found that digital technologies in the Nigerian construction industry during the pandemic were not as successful as those in developed countries. Similarly, Bikse et al. (2021) established that Latvian SMEs struggled to adapt to the changing economic climate by modernizing their processes and integrating digital transformation at the pace required. However, the pandemic inspired Nigerian construction stakeholders to reconsider using digital technologies (Ebekozien & Aigbavboa, 2021).

There were no studies conducted on the effect of the Covid-19 pandemic on digital transformation or the adoption of its associated technology, such as e-procurement in South Africa. Thus, it is worth investigating the drivers of e-procurement before the pandemic to understand the situation and gather data on how it compares post the onset of the pandemic.

2. 3 Drivers to the adoption of e-procurement

The results of a literature review examining the drivers of e-procurement in the construction industry are presented in Table 1.

Table 1. Drivers to the adoption of E-procurement obtained from Literature Review

Drivers of the adoption of E-procurement	**Driver Category**	Rankin, Chen and Christian (2006)	Laryea and Ibem (2014)	Ibem and Laryea (2015)	Ibem and Laryea (2017)	Eadie, Perera and Heaney (2010)	Li et al. (2015)	**No. of times cited**
		Authors						
D1_Reduce process, transaction and administrative cost	Technology and process level	X		X		X		3
D2_Reduce cycle times for process and transaction	Technology and process level	X		X		X		3
D3_Improve response, accuracy and flexibility of the process	Technology and process level	X				X		2
D4_Ease of use of technology	Technology and process level			X			X	2
D5_Reduces paperwork	Technology and process level	X		X				2
D6_Increase trust, reliability of the process	Technology and process level			X				1
D7_Improve quality of the process	Technology and process level					X		1
D8_ External pressure from business partners	External						X	1
D9_Enhanced inventory management	Project level					X		1
D10_Wider access to suppliers	Project level	X						1

The drivers of the adoption of e-procurement shown in Table 1 are distributed into categories such as Technology and process, Project, External, Individual and Company levels as defined by Yevu and Yu (2019) and Li et al. (2015). Though other studies, such as Eadie, Perera and Heaney (2010) and Ibem and Laryea (2015), also defined categories to split the drivers. However, there was no explanation of what the different categories meant. For example, there was a General category (Eadie et al., 2010) which had some diverse drivers that could be split into better-defined categories.

Table 1 illustrates that the Technology and process level category has the most drivers. This category describes the benefits e-procurement brings to the process of procuring projects (Yevu & Yu, 2019). The top five cited drivers are: reducing process, transaction and administrative costs; reducing cycle times for process and transaction; improving response, accuracy and flexibility of process; ease of use of technology and reducing paperwork (Rankin, Chen & Christian, 2006; Ibem & Laryea, 2015; Eadie et al., 2010; Li et al., 2015) and they fall within this category.

The categories with the second most drivers of e-procurement, as seen in Table 1, are the Company level and Project level categories. The Company level category also referred to as the Organizational category (Li et al., 2015), refers to drivers that inspire management to take up e-procurement (Yevu & Yu, 2019), and examples include gaining a competitive advantage' and compatibility of technology to the company goals, among others. The Project level category refers to the benefits that can be enjoyed (at the project level) when e-procurement is used (Yevu & Yu, 2019). Examples include archiving convenience and enhanced inventory management (Eadie et al., 2010). The description of the Project level drivers matches that given for the Technology and process level drivers, and the drivers identified in both categories appear to be benefits.

The categories with the third most drivers are External level and Individual level – each category had two drivers. The External category refers to drivers influenced by external bodies or organizations involved in promoting e-procurement (Yevu & Yu, 2019). Examples include external pressure from business partners and the availability of policies promoting e-procurement (Ibem & Laryea, 2015; Li et al., 2015). The Individual category refers to drivers which describe how people are motivated to promote the adoption of e-procurement (Yevu & Yu, 2019), and examples include staff which is adaptable and keen to use technology and available staff expertise in technology systems (Ibem & Laryea, 2015; Li et al., 2015).

It can be deduced from the literature that the top drivers to the adoption of e-procurement as identified in the literature are: reduction of transaction, process and administrative cost; reduce cycle times for procurement processes and transactions; improve response, accuracy and flexibility of process; ease of use of the technology and reduced paperwork. However, the drivers do not include Covid-19, which is the focus of this research.

3. Research Methodology

The research adopts a quantitative approach because the research objective is based on the positivist philosophy. The study population consists of active construction organizations in South Africa listed in Grades 7 to 9 on the Construction Industry Development Board (cidb) Register of Contractors (RoC); this is because these companies are the ones with the most significant turnover and available capital and are thus the most likely to be able to afford e-procurement software. Table 2 shows the minimum turnover, minimum available capital and population numbers across Grades 7 to 9 on the cidb RoC.

Table 2. Details of active construction companies with cidb grade of between 7-9

Company grade level	Annual turnover	Available Capital	No. of active companies
7	R20 000 000	R4 000 000	1197
8	R65 000 000	R13 000 000	561
9	R200 000 000	R40 000 000	227
Total population			1985

Source: cidb (2022)

The research used the random sampling technique in selecting 322 active companies from the cidb RoC determined using the formula for calculating the sample size in Saunders, Lewis and Thornhill (2009). The research employed an online questionnaire survey in data collection because it offers convenient access to the respondents and is suitably aligned with the quantitative research approach and positivist philosophy adopted in the study. Seventy-five responses were received at the end of the survey period representing a response rate of 23.3% which is in line with the response received for the questionnaire in construction research of 20% - 30% (Akintoye & Fitzgerald, 2000).

The questionnaire sought to find out the profession, years of experience, highest education level and company location of the respondents, and the level of use of e-procurement before and after the onset of Covid-19 which required 'yes' and 'no' responses- as well as another two on whether Covid-19 caused an uptake in the use of e-procurement, and the drivers of e-procurement. Respondents expressed their perceptions about the influence of the identified drivers from the literature on adopting e-procurement using a 5-point Likert scale ranging from 1 (no influence) to 5 (strong influence).

Two methods of data analysis – descriptive and inferential statistics were used in analyzing the data collected. Types of descriptive statistics used were percentages and frequencies. The drivers were after that rated using the Mean Item Score (MIS) method of descriptive analysis (see Equation 1).

$$MIS = \frac{5M_5 + 4M_4 + 3M_3 + 2M_2 + 1M_1}{5 \times \left(M_5 + M_4 + M_3 + M_2 + M_1 \right)} \quad (1)$$

Where M_5, M4, M_3, M_2 and M_1 are frequencies of the rating responses given to each driver.

The Cronbach's Alpha test was used to determine the level of reliability. The Cronbach Alpha test determines the level of internal consistency among individual responses to questions. A value of 0.7 or above indicates high reliability (Saunders, Lewis & Thornhill, 2009). Table 3 shows the Cronbach Alpha values for those scales and the number of items making up that scale. All Cronbach alpha values are above 0.7 and therefore indicate high reliability.

Table 3. The Cronbach Alpha reliability results for different scales

Scale	Cronbach's Alpha	Cronbach's Alpha based on standardized items	Number of items
Covid-19 influence on e-procurement adoption	0.864	0.881	2
EP drivers before Covid-19 onset	0.942	0.942	8
EP drivers after Covid-19 onset	0.953	0.953	8

In order to ensure construct validity, the questionnaire questions were formulated from a framework of drivers of e-procurement adoption developed from an extensive literature review. Ethics clearance has to be sought in accordance with the Ethics requirements for the Engineering and Built Environment faculty at the University of Cape Town. A pre-screening questionnaire was completed, establishing that full ethics clearance was needed for this study as it involved human participants. After submitting the required documents, ethics approval was granted for the research.

4. Data Presentation, Analysis and Discussion

4. 1 Background details of the respondents and the companies represented

The study sought to know the background details of the respondents and companies represented. The data collected shows that the highest percentage (49.33%) of respondents identified themselves as Contractors; the majority of respondents (31.88%) have more than 20 years of experience; and most respondents (34.78%) are holders of a diploma. Also, the highest number of respondents (34.78%) work for companies that are in the Gauteng province of South Africa, and the majority of the companies (44.93%) have an annual turnover of less than R20 million ($1.1 million).

4.2 Adoption of e-procurement before and after the onset of Covid-19

The study sought to know the level of use of e-procurement before and after the onset of Covid-19, and the data collected in this regard is presented in Table 4.

Table 4. E-procurement use before and after Covid-19.

Options	Yes	No	Total Response
E-procurement use before the onset of Covid-19	45.10% 23	54.90% 28	51
E-procurement use after the onset of Covid-19	60.78% 31	39.22% 20	51

The findings presented in Table 4 indicate that 45.10% of the respondents used e-procurement before the onset of Covid-19, and that figure rose to 60.78% after the onset of Covid-19.

4.3 Perceived Impact of Covid-19 on the adoption of e-procurement

The data shows that most respondents (42.86%) viewed that Covid-19 caused an increase in the adoption of e-procurement, with a lesser number (34.69%) viewing that it had no influence, in other words, the adoption of e-procurement stayed the same. In comparison, 22.45% of the respondents viewed that Covid-19 affected the adoption of e-procurement negatively.

4.4 Drivers impacting the adoption of e-procurement pre and post onset of Covid-19

The study sought the respondents' opinions on the drivers impacting the adoption of e-procurement pre and post onset of Covid-19. The data collected in this regard is rated on a scale of 1 to 5, where 1 = No Influence and 5 = Very High Influence and analyzed using the Mean Item Score presented in Tables 5 and 6, respectively.

The findings indicate in Table 5 that respondents perceived from a ranking perspective that the top four drivers influencing the adoption of e-procurement before the onset of Covid-19 are ‘improved flexibility’ and ‘improved response time’ of the procurement process, ‘Reduction in cycle times for processes and transaction’ and ‘reduction of paperwork within the contracting or client company’.

Table 5. Drivers of e-procurement adoption before the onset of Covid-19

E-procurement drivers before the onset of Covid-19	Influence of Driver					Total Response	Total Score	MIS Score	Rank
	Very Low	Low	Average	High	Very High				
Improved flexibility of the procurement process	8	6	10	5	4	33	90	0.545	1
Improved response time of the procurement process	10	5	11	5	3	34	88	0.518	2
Reduction in cycle times for processes and transaction	10	6	10	2	5	33	85	0.515	3
Reduction of paperwork within the contracting or client company	9	7	9	3	4	32	82	0.513	4
Improved accuracy of the procurement process	10	5	11	5	2	33	83	0.503	5
Availability of policies promoting e-procurement	10	6	10	4	3	33	83	0.503	5
Reduction in process, transaction and administrative cost	9	10	6	6	2	33	81	0.491	7
Ease of use of e-procurement technology	12	8	8	3	2	33	74	0.448	8

Table 6. Drivers of e-procurement adoption after the onset of Covid-19

E-procurement drivers after the onset of Covid-19	Influence of Driver					Total Response	Total Score	MIS Score	Rank
	Very Low	Low	Average	High	Very High				
Improved response time of the procurement process	9	5	3	5	5	27	79	0.585	1
Improved flexibility of the procurement process	7	6	4	4	6	27	77	0.570	2
Reduction of paperwork within the contracting or client company	9	4	5	0	9	27	77	0.570	2
Improved accuracy of the procurement process	10	6	3	2	5	26	70	0.538	4
Availability of policies promoting e-procurement	9	5	4	6	3	27	70	0.519	5
Reduction in cycle times for processes and transaction	10	5	4	5	3	27	67	0.496	6
Ease of use of e-procurement technology	12	3	3	5	4	27	67	0.496	7
Reduction in process, transaction and administrative cost	9	7	4	4	3	27	66	0.489	8

Table 6 indicates that from a ranking perspective, the respondents perceived that the drivers of e-procurement adoption after the onset of Covid 19 are ‘improved response time’, and ‘improved flexibility of the procurement process’, ‘reduction of paperwork within the contracting or client company’ and ‘improved accuracy of the procurement process.’

The data presented in Tables 5 and 6 show a similarity in the respondents' perception of the key drivers influencing the adoption of e-procurement on construction projects. The respondents were of the view that 'improved flexibility' and 'improved response time of the procurement process' are the two top drivers of the adoption of e-procurement before and after Covid-19, and ‘reduction of paperwork within the contracting or client company’, the only difference being in their ranking.

5. Discussion and findings

It emerged from the study that e-procurement adoption saw an increase from pre-Covid-19 figures. While 45.1% of the respondents stated that they used e-procurement before the onset of Covid-19, 60.7% used it after the onset of Covid-19. The last reported e-procurement adoption rate for the SA construction industry stood at 11%, based on data collected in 2004 (Ibem & Laryea, 2015), indicating an increase in its uptake. A similar study recently reported EP adoption in Nigeria at 69.5% (Ibem et al., 2021); thus, at 60.7%, SA is now comparable with other African countries.

Before the onset of Covid-19, respondents perceived from a ranking perspective that the drivers of e-procurement adoption after the onset of Covid 19 are ‘improved flexibility’ and ‘improved response time’ of the procurement process, ‘Reduction in cycle times for processes and transaction’ and ‘reduction of paperwork within the contracting or client company’. After Covid-19, the respondents perceived from a ranking perspective that the key drivers of e-procurement are ‘improved response time’, and ‘improved flexibility of the procurement process’, ‘reduction of paperwork within the contracting or client company’ and ‘improved accuracy of the procurement process.’ There was no ranking conducted in previous research, but it does make sense that the adoption of a technology that leads to a reduction in paperwork (Rankin et al., 2006; Ibem & Laryea, 2015) and one that improves the response and flexibility of the procurement process (Rankin et al., 2006; Eadie et al., 2010) both technology and process level drivers, would be perceived by the respondents as critical drivers of the adoption of e-procurement notwithstanding the onset of Covid-19. This result was unexpected since ‘Reduction in process, transaction and administration cost’ was noted as a top driver in previous studies by Ibem and Laryea (2017).

Based on these findings, Covid-19 was found not to significantly influence the adoption of e-procurement, meaning it did not cause the e-procurement adoption rate to improve because the perceived key drivers did not change significantly between the period before and after Covid-19. Since there is an increased percentage uptake in both e-procurement adoption post-Covid-19, as shown in Table 5, regardless of Covid-19 itself being a cause- this points to other drivers being more influential, thus resulting in this increased adoption rate.

6. Conclusions and recommendations

This research examined the drivers to adopting e-procurement in the South African construction industry (SACI) before and after the onset of the Covid-19 pandemic. It emerged from the study that there was an increase in the use of e-procurement before and after the onset of Covid-19. The findings also showed no significant difference in the key drivers influencing the adoption of e-procurement before and after the onset of Covid-19; the only difference seen was in the ranking of the drivers. The results indicate that e-procurement adoption grew past the onset of Covid-19 and appears not to influence its adoption significantly. Based on these findings, the study concludes that the adoption of e-procurement on construction projects will grow with the need of clients to make the procurement process more flexible, timeous and reduction in the paperwork used, and recommends increased flexibility of the procurement process to allow for the adoption of electronic means of procurement towards improving the competitiveness of the SACI and its currency.

This study would have been better suited as a longitudinal study where the respondents would have been questioned at different points in time: before and after the onset of Covid-19. Also, respondents may be affected by recall bias (participants' remembrance of exposure to a phenomenon differs based on their outcome status, and vice-versa); the researchers may find it difficult to measure cause and effect, and the timing of the study may not be representative of the phenomenon.

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Impact of COVID-19 on the Construction Industry: A Case-Study of Disruptions and Recovery Strategies

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Abstract

The COVID-19 pandemic spread worldwide and affected almost all countries globally. The continuous spread of the virus has had significant impacts on most sectors of the economy, including construction. The construction industry faced severe challenges, such as labor shortages, material shortages, cost escalations, schedule delays, delayed permits, approvals, inspections, travel restrictions, and serious health and safety concerns among others which hindered the timely delivery of the construction projects. As a result, owners were under immense pressure, especially in the public universities as there were limited buildings to accommodate the increased teaching and research activities to meet the current and future needs. However, to date very limited research has been conducted on it. Therefore, this research aims to investigate and understand the challenges faced by contractors and owners due to the pandemic, and what actions were taken for the timely delivery of their Capital Improvement Projects (CIP) to facilitate teaching and research activities. The study employed a case-study based approach to investigate the impact of COVID-19 on a public project at a university in the southeast region of the U.S. The results show that both the contractor and the owner worked together to complete the project, but the owner had to come up with innovative solutions to overcome the critical issues while still risking the timely delivery of the project.

Keywords

COVID-19 Impact, Construction Industry, Owners, Contractors, Public Projects, Case Study.

1. Introduction

The COVID-19 pandemic spread worldwide and affected all countries globally. The virus was first identified in December 2019 in Wuhan, China. Several countries, and organizations like the Centers for Disease Control (CDC) cautioned the public to take responsive care such as handwashing, wearing face masks, physical distancing, and avoiding mass gatherings and assemblies. Lockdown and staying-at-home strategies were put in place to control the transmission of the disease (Sintema, 2020). Even with these preventive measures, the virus continued to spread and brought most of the globe to a halt, toppling the world economies. The pandemic has affected the global economy and, thus, the global construction industry (Rehman et al., 2021). During this global pandemic, contractors and their sureties have faced numerous challenges, such as labor and material shortages, extensive cost escalations, extensive lead time, delayed inspections and permits, etc. (Rehman et al., 2021). These impacts have led owners, contractors, subcontractors, and developers to exercise their contractual rights to mitigate risks for themselves and their companies.

In the United States, businesses deemed as "non-essential" had to completely halt in-person activities and encouraged telecommuting or "work from home" systems. However, construction was deemed as "essential" and was allowed to carry on regular construction activities as long as they complied with the CDC guidelines (Salman et al., 2021). Even with such leniency, the construction industry faced critical challenges such as delays and suspension of existing projects; cancellation of planned and new projects; supply chain complications; production delays and logistic bottlenecks; creation of additional and new risks related to the job sites, and contractual responsibilities; labor shortages, health and safety of construction workers; and financial issues like limited capital availability (Morris et al., 2020). As a result, owners were under immense pressure, especially in the public universities as there were limited buildings to accommodate the increased teaching and research activities to meet the current and future needs. Some studies have explored the impact of COVID-19 on the construction industry (Biswas et al., 2021), but none of these studies focused on the impact of COVID-19 in a public university setting where the contractor must provide and complete the building in the given time period to facilitate teaching and research needs of various programs. This research aims to investigate and understand the challenges faced by contractors and owners due to the pandemic and develop a list of actions taken for the timely delivery of Capital Improvement Projects (CIP) to facilitate teaching and research activities in the higher education environment. The study employed a case-study approach. Both quantitative and qualitative data were collected and analyzed. Request for Information (RFI) data was collected from the owner and contractor to quantitatively assess the number of COVID-related RFIs. Interviews were conducted with contractor representatives and owner representatives to explore the strategies adopted to tackle the issues (found from the quantitative data analysis) and their effectiveness during the pandemic.

2. Literature Review

Many studies have been conducted to explore the impact of COVID-19 on the construction industry from the contractor's perspective (Biswas et al., 2021; Sami Ur Rehman et al., 2021). For example, Rehman et al., (2021) found that the UAE construction industry faced several challenges such as schedule delays, disrupted cashflows, delayed permits, delayed approvals and inspections, travel restrictions, serious health and safety concerns, material, equipment shortages, etc., which hindered the timely delivery of construction projects. A survey conducted by the American Society of Civil Engineers (ASCE), reported the following facts:

- 20% of the organizations had to retract offers to entry-level employees and interns.
- 14% of the organizations were facing potential contract penalties due to project delays.
- 50% of the companies have experienced COVID-19 related delays in receiving material and products from suppliers; and despite the gradual reopening of the national economy, 29% of companies expressed concerns over their long-term viability.

Additionally, these organizations were met with several challenges, including but not limited to, cancelation or delay of contracts, cash flow challenges, hiring freezes, absenteeism, supply chain shortages, layoffs, and furloughs (Stover et al., 2020). Schedule delays have been an issue in the construction industry even from the pre-pandemic time. Al-Wadei (2020) examined several sources to identify the different causes of schedule delays for projects worldwide, with the main focus being on oil and gas projects. Only 52% of projects were completed on time in 2018 and this has remained around 50% between 2011-2018 (Al-Wadei, 2020). Late projects led to cost overruns of thousands of dollars per day for capital projects. The primary causes of project schedule delays were changes within the organization such as changes in the priorities, project objectives, and inaccurate scope requirements. This issue was exacerbated during the pandemic when the manufacturers did not have enough workers to complete the jobs (Castenson, 2021). Another study explored ways for builders, developers, manufacturers, architects, and contractors to overcome supply chain issues by creating a successful path forward with their respective projects. The study proposes to prefabricate certain items before reaching the job site, which not only reduces the direct cost of the project but also solves the labor shortage issue (Stover et al., 2020).

During the pandemic, projects were experiencing an increase in overall cost for several reasons. For example, due to the pandemic, there was a need for additional staff on the job sites to implement new safety guidelines and perform temperature checks, and other activities required or recommended to maintain a healthy work environment (Stover et al., 2020). There was also a need for additional handwashing stations. Labor shortage due to absenteeism was due to several factors such as the quarantine period, issues with public transportation, lack of available childcare, etc. Furthermore, telecommuting; and the reduced on-site staff mandate or government-mandated social distancing also contributed to the labor shortage and a decrease in labor productivity resulting in schedule delays (Stover et al., 2020).

Additionally, the supply chain within the construction industry was highly impacted due to the pandemic. As more countries were under government-mandated lockdowns, manufacturers were fabricating raw materials at a much slower pace which made it hard for vendors to procure materials on time; such challenges were hindering construction work all across the United States (Biswas et al., 2021). Furthermore, material procurement became more expensive as a result of global manufacturing shutdowns (e.g., products made in China), international borders and port shutdowns, and general material transportation delays within the United States (Stover et al., 2020). Due to such issues, lower-tier contractors, subcontractors, and vendors suffered great losses which in turn affected several bonded projects. A research study projected that materials shortages could put the brakes on construction activity, leading to a lack of supply in 2022 and beyond. The study explains that the cost escalations of steel, lumber, and other essential materials are understated and do not present the severity of the problem (Biswas et al., 2021).

Research Gap

There has been significant research worldwide related to the impact of the pandemic on the construction industry, however, very limited studies were conducted in the United States. Additionally, none of the studies go at a micro level to understand the impacts. Collectively many researchers did not communicate with any stakeholders i.e., owners, architects, or contractors to get their perspective to address the COVID-19 challenges. Research should be conducted with each of these stakeholders to analyze the issues and successful mitigation strategies (Biswas et al., 2021). Therefore, this research conducts interviews with the contractor and the owner to document the strategies adopted and their effectiveness.

3. Methodology

The study employed a case-study approach and both quantitative and qualitative data were collected to investigate the impact of COVID-19 on a project at a university in the SE region. The RFI data was collected from the contractor and the owner which was quantitatively analyzed to assess the percentage of COVID-19 related RFIs, their solutions, and their impact on the project schedule. Following the quantitative analysis, interviews were conducted to inquire about the strategies adopted to mitigate the COVID-19 related issues with the contractor as well as the owner representatives. Eight semi-structured interviews were conducted; four from the contractor side and four from the owner side to gain both perspectives. The interview questions are given in Table 1. The interview data was analyzed using thematic analysis.

Table 1. Interview Questions

Sr. No.	Interview Questions
1	Since March 13th, 2020, how significant were the impacts of the COVID-19 pandemic on project cost and time of XYZ project? And what were they?
2	When did you first start seeing the impacts of COVID-19 on the project? Describe them.
3	When did COVID-19 start impacting the supply chain/ material procurement for this project? How did you resolve the issue?
4	What were the top 3 materials/items on the project that were affected? Were the prices locked? Did the increase in prices affect this project? How did you resolve the issue?
5	What impacts of COVID-19 did you anticipate and what changes did you implement when a national emergency was declared on March 13th, 2020, and when the industry was deemed "essential"?
6	What would you say are the lessons learned from COVID-19 that you could apply to all future projects?
7	Any advantages that come to mind? And what would you do differently if you had to prepare for another pandemic?

Case-Study Project

The project selected for the case-study is an academic building. Besides teaching and research, the selected project also blends in retail, restaurants, apartment units, and a luxury hotel in the heart of the town. The 142,000-square-foot complex is designed to promote immersive learning experiences for students pursuing careers in hospitality and culinary sciences. The project started in March 2020 and was severely impacted by COVID-19. The total cost of the project was $110 million. The data for the case-study was provided by the contractor and owner. The RFI data (Appendix A) was quantitatively analyzed to determine the level of COVID-19 impact on the project. Interviews were conducted with the contractors and owners to understand the COVID-19 impact on the project and strategies adopted to mitigate the impact on project completion.

3. Results

For the case-study, 51 RFIs (request for information) were analyzed between 2020 and 2021. The RFIs were first categorized by sub-contractors. Upon preliminary analysis, it was evident that the companies were subjected to the challenges of material procurement, cost escalations, labor shortages, and supply chain. The language of the RFIs also pointed out the impacts of the pandemic on this project, which predominantly affected either project cost or project time. To quantify all the data available in RFIs, content analysis was conducted. Firstly, all data were categorized based on the types of impacts on the project. For example, supply chain implications such as material shortages and cost escalations; or workforce related issues such as labor shortages, as indicated by the vendor or subcontractor. These categories were then dissolved into the base impacts on project cost and/or project completion time. Lastly, it was determined if the sub-contractor or vendor has listed the RFI as a direct effect of COVID-19 or not. The date the RFI was sent to the contractor and the date the changes were implemented were also noted. Once all data was examined through these parameters, major impacts were identified. Appendix A shows the detailed RFIs analysis.

3.1 Quantitative Analysis of RFIs

Out of the fifty-one (51), RFIs sent to the GC, forty-four (44 or 86%) reported that the challenges faced were a direct impact of the COVID-19 pandemic. The other instances (total 7 or 14%) where they faced challenges were due to supply chain backlog caused by hurricanes.

Reported Impacts

In this case study, out of the fifty-one instances, the most common impacts of COVID-19 were: (i) cost escalations, (ii) material shortages, (iii) labor shortages, and (iv) an increase in lead times; as shown in Table 2.

Table 2. *Reported COVID-19 impacts and respective frequency*

Reported Impacts	Instances Recorded	Total Instances
Cost Escalations	41	51
Material Shortages	30	51
Labor Shortages	18	51
Increase in lead times	21	51

Materials Shortages and Cost Escalations:

The pandemic caused significant challenges for supply chains globally, disrupting the flow of raw materials and finished goods. Current research shows that this disruption is initiating a global shortage of raw building materials, resulting in cost escalations and extended lead times (Biswas et al., 2021). Such challenges also affected the construction of this project. Several material vendors expressed that the pandemic has resulted in product costs skyrocketing. The most common materials affected, and the magnitude of cost escalation reported are presented in Table 3.

Table 3. Materials affected, and total percent of reported cost escalation calculated

Materials Affected	Instances recorded	Total Instances	Total % of Cost Escalation
Steel	24	51	272%
Gypsum	4	51	263%
Insulation	17	51	126%

3.2 Qualitative Analysis of Interview Data

A total of eight interviews were conducted, four with the contractor and four with the owner’s team to explore the mitigation strategies from both sides. The information obtained from these interviews provided similar results, and the consensus was that the COVID-19 pandemic had a significant impact on this project's cost and schedule. Interview questions are shown in Table 1. Thematic analysis was performed on the collected data to explore the specific impact and adopted strategies. Results from data analysis of interview questions have been summarized, analyzed, and presented in this section. Based on the interviews, the contractor faced many issues such as extended lead time, material procurement, cost escalation, labor shortages, health concerns, and contractual issues. Some responses also informed about benefits due to COVID-19 i.e., better collaboration between the project stakeholders since everyone was available remotely, all stakeholders were able to use the technology to communicate, and the workplaces became cleaner due to health concerns. Both the contractor and the owner had shared and unshared issues, explained below:

Extended Lead Time and Material Procurement

Table 4 describes a summary of the issues from the contractor, owner, and the strategies to overcome those challenges. The data analysis shows that the owner had provided assistance in resolving most of the issues discussed in Table 4. For example, in the case of extended lead times and material procurement, the owner had provided a conditioned storage space to procure the material ahead of time and be stored until it is ready to be used on-site. The cost of the storage space was absorbed by the owner. The contractor and the owner had informed difficulty procuring material from Europe, specifically Italy and Germany simply because the factories were closed during the pandemic and later opened with limited workers. One interviewee said, "Supply chain issues will continue to plague all industries until skilled labor and manufacturing plants are back to normal capacity, which will take years to accomplish due to the massive backlog of materials".

Cost Escalation

All responses reported cost escalation of many raw materials as well as other components. Moreover, the project being a hard bid public project, the owner was unable to facilitate any request of contract modification to accommodate the increased prices. However, any change orders were made at the escalated prices.

Labor Shortages and Health Concerns

The contractor had reported labor shortages and health concerns for the project team. The project team was allowed to work remotely or have limited individuals in the trailer. There were health concerns for onsite workers. The owner resolved the issue by creating an on-site health and safety guidelines which the contractor followed.

Table 4. Results of Interviews with contractor and owner teams.

Contractor	Owner	Strategy Adopted
-Extended lead times -Material procurement	-Extended lead times -Material procurement -Lighting fixtures, Flooring -Furniture procurement	-Owner provided a conditioned warehouse to procure the materials ahead of time to avoid schedule delays.
-Cost escalation in material prices		-Nothing done for the cost escalation due to a hard bid project. -Any change orders were made at the escalated cost.
-Subs and vendors experienced extensive amounts of labor shortages		- Construction site health policy was established by the owner.
-Health concerns	-Health concerns	
-Delayed project completion	-Delayed project completion -Challenge of starting the new semester and accommodating teaching and research activities	-Partial substantial completion was requested
-Contractual issues: Liquidated damages	- Owner was impacted by the delayed completion	-Owner considered it an act of God and did not employ any liquidated damages

Delayed Project Completion

In order to start the academic semester, the owners had requested partial substantial completion to continue the teaching and research activities. Although the building was not fully complete, the owner was granted partial substantial completion. The owner said, "Typically, we wait to open a building, but in this case, we had to start the academic year. We couldn't move the start of the school year. We held out on the hotel and the lease living units because those weren't up against a hard date". The owner's responses also informed many issues due to the early opening as presented in this comment, "if there was one thing I would do differently, for a job this size, it would be delayed opening until the spring semester. That would've given the contractor time to work off the punch list". In addition, the owners reported issues with procuring furniture which is still a challenge. The owners had resolved the issue by having temporary furniture in the building until the original is delivered.

Contractual Issues

The contractor presented their concerns about liquidated damages in case of project delay. Although the project was delayed and the owner faced many challenges, however, the owner considered them an "act of God" and did not exercise their contractual right of liquidated damages.

4. Future Research

The results presented a series of challenges in the construction industry i.e., material shortage, labor shortage, cost escalation, and increase in lead time causing delays. The future phases of this research should include multiple projects in the region to investigate whether similar issues were faced in those projects. Based on that, a framework of best practices should be developed to prepare owners for future outbreaks/epidemics/pandemics and have an action plan to follow in times of crisis. Furthermore, future research should also address the issue of material procurement by using AI-driven software which can inform the stakeholders about real-time construction lead times. This can help contractors and owners to track materials/items in real-time and resolve them during their planning and procurement stages.

5. Conclusions

This research investigated the impact of COVID-19 on a construction project in a public university setting and presented the actions taken for the timely delivery of their Capital Improvement Projects (CIP) to facilitate teaching and research activities. The study employed a case-study approach in which both quantitative and qualitative data were collected. The results showed that the pandemic had negative impacts on the construction industry, such as labor shortage, increase in unemployment levels, material and equipment issues and, new contractual risks. Some positive impacts were also reported like increase in technology adoption, better collaboration between the project stakeholders, cleaner workplaces and job sites, and a shift towards more reliance on diversified local suppliers. It also shows that during the time of crisis the owner fully supported the contractor in resolving most of the issues. The case study shows that both the contractor and the owner worked together to complete the project, but the owner had to come up with innovative solutions to overcome the critical issues while still risking the timely delivery of the project. Future research should focus on developing best practices framework that contractors and owners can follow in times of crisis.

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Appendix A: Quantitative data analysis for the RFIs Results

Data Analysis: Raine Culinary Center - RFI's											
No.	Company	Material	Reason for RFI: Changes in Cost: Price Increase	Material Shortage	Labor Shortage	Changes in Time	Change in Price	Products with changes in price	Effect of COVID?	When was it sent?	When is it implemented?
1	USG	Gypsum	1	0	0	0	20%	All wallboard products, including Sheetrock® Wallboard products and Securock® Glass-Mat products.	1	5/3/2021	6/1/2021
							5%	Durock® brand cement board and glass mat tile backer and Fiberock® brand			
							5%	All interior finishing products, which includes all Joint Compound,Tape, Texture, Plaster and Accessories			
							10%	All bead and trim products which includes all Paper-Faced Bead &Trim and Metal Bead products.			
							$2/roll	Fiberock® brand Floor Protector Paper			
2	American Gypsum	Gypsum	1	0	0	0			1	3/5/2021	4/5/2021
3	ClarkDietrich	Steel	1	1	1	1	10%	All steel products	1	2/1/2021	4/1/2021
4	ClarkDietrich	Steel	1	1	1	1	10%	All steel products	1	12/1/2020	1/4/2021
5	ClarkDietrich	Steel	1	1	1	1	10%	All steel products	1	12/28/2020	2/1/2021
6	ClarkDietrich	Steel	1	1	1	1	10%	All steel products	1	12/28/2020	3/1/2021
7	ClarkDietrich	Steel	1	1	1	1	10%	All steel products	1	3/4/2021	5/3/2021
8	ClarkDietrich	Steel	1	1	1	1	10%	All steel products	1	3/18/2021	6/1/2021
9	ClarkDietrich	Steel	1	1	1	1	10%	All steel products	1	5/3/2021	7/1/2021
10	ClarkDietrich	Steel	1	1	1	1	10%	All steel products	1	9/28/2020	11/1/2020
11	ClarkDietrich	Steel	1	1	1	1	10%	All steel products	1	10/29/2020	11/30/2020
12	CertainTeed	Gypsum	1	1	0	0	5%	All interior finishing products, which includes all Joint Compound,Tape, Texture, Plaster and Accessories	1	5/7/2021	6/7/2021
							10%	Corners products			
13	CertainTeed	Gypsum	1	0	0	0	20%	All core and specialty wallboard products	1	5/7/2021	6/7/2021
							40%	All value added wallboard products	1		
							$200/msf	shaftliner products	1		
14	CertainTeed	Gypsum	1	0	0	0	20%	All Wallboard products	1	2/17/2021	4/1/2021
15	CertainTeed	Gypsum	1	0	0	0	20%	All Wallboard products	1	10/26/2020	1/4/2021
							5%	All compunds, poweders, textures, sprays, glues and tapes	1		
16	CertainTeed	Gypsum	1	0	0	0	6%	Joint compunds,setting compounds, all primers, paints, textures,tape	1	3/17/2021	4/9/2021
17	CertainTeed	Gypsum	0	1	1	1			1	4/29/2021	4/29/2021
18	CertainTeed	Gypsum	1	0	0	0	12%	All Wallboard Products	1	9/18/2020	10/16/2020
							5%	All compunds, poweders, textures			
19	Cemco	Steel	1	1	0	0		All Steel Products	1	5/24/2021	5/25/2021
20	Georgia Pacific	Gypsum	0	0	0	1		Toughrock and Dens Availability	1		5/20/2021
21	Johns Manville	Insulation	0	1	0	1		Light density fiberglass products	0	3/4/2021	3/4/2021
22	Johns Manville	Insulation	1	0	0	0	4%	All residential and commercial Batt & Roll products	0	8/12/2020	10/1/2020
							4%	PSK & FSK			
							4%	Basement Wall			
							4%	All loose fill blowing wool products			
							4%	All manufactured housing products			
							4%	All metal building products			
							4%	Insul-Shield			
23	Johns Manville	Insulation	1	0	0	0	8%	All residential and commercial Batt & Roll products		2/19/2021	4/26/2021
							12%	R-15, R-21			
							8%	FSK & PSK, basement wall, All loose-fill blow-in fiberglass products, all manufacturing housing products			
							8%	All metal building products, Insul-SHIELD, MinWool Sound and fire block, TempControl All R-values			
							6%	MinWool Sound Attenuation Fire Batts, MinWool Curtainwall, Safing, JM Cladstone Water and fire block			
24	Johns Manville	Insulation	1	0	0	0	8%	All residential and commercial Batt & Roll products	0	5/7/2021	9/1/2021
25							8%	PSK & FSK			
26							8%	Basement Wall			
27							8%	All loose fill blowing wool products			
28							8%	All manufactured housing products			
29							8%	All metal building products			
30							8%	Insul-Shield			
31	MarJam Supply Co.	Building Materials	1	1	1	1		All materials	1	5/24/2021	5/24/2021
32	Marino Ware	Steel	1	1	0	0	15%	All steel products	1	4/30/2021	6/1/2021
33	Marino Ware	Steel	1	1	0	0	10%	All steel products	1	5/28/2020	7/1/2020
34	Marino Ware	Steel	1	1	0	0	20%	All steel products	1	3/23/2021	5/4/2021
35	Marino Ware	Steel	1	1	0	0	10%	All steel products	1	12/1/2020	1/4/2021
36	Marino Ware	Steel	1	1	0	0	10%	All steel products	1	8/31/2020	10/1/2020
37	Marino Ware	Steel	1	1	0	0	10%	All steel products	1	10/30/2020	12/1/2020
38	Marino Ware	Steel	1	1	0	0	10%	All steel products	1	2/1/2021	4/1/2021
39	Marino Ware	Steel	1	1	0	1	10%	All steel products	1	4/16/2021	4/16/2021
40	Marino Ware	Steel	1	1	0	0	10%	All steel products	1	1/2/2020	2/3/2020
41	Marlite	Building Materials	1	0	0	0	7%	FRP PVC Trim	1	4/6/2021	5/3/2021
42	National Gypsum	Gypsum	0	1	1	1		ProForm Products	1	3/17/2021	3/22/2021
43	National Gypsum	Gypsum	1	0	0	0	15%	All gypsum wallboard products	1	9/18/2020	10/19/2020
							5%	All ProForm Finishing Products			
44	National Gypsum	Gypsum	1	0	0	0	20%	All Gold Bond Gypsum Wallbard Products	1	3/5/2021	4/5/2021
							5%	All ProForm Interior Finishing Products			
							5%	All PermaBASE Cement Board Products			
45	National Gypsum	Gypsum	1	0	0	0	15%	All Gold Bond Gypsum Wallbard Products	1	5/7/2021	6/7/2021
							5%	All ProForm Interior Finishing Products			
							5%	All PermaBASE Cement Board Products			
							5%	All Gold Bond Plaster Products			
46	SPECON Systems	SUB	1	1	1	1			1	5/28/2021	5/28/2021
47	ClarkDietrich	Steel	1	1	1	1		All steel products	1	5/10/2021	5/10/2021
48	LGH	Steel	1	1	1	1	6%	All steel products	1	4/1/2021	5/31/2021
49	LGH	Steel	1	1	1	1	19%	All steel products	1	6/1/2021	7/31/2021
50	LGH	Steel	1	1	1	1	24%	All steel products	1	8/1/2021	9/30/2021
51	LGH	Steel	1	1	1	1	28%	All steel products	1	10/1/2021	12/31/2022

Building Information Modelling for Construction Project Planning: Benefits to the South African Construction Industry

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Abstract
Building Information Modelling (BIM) is an intelligent environment utilised by the Architecture Engineering and Construction Industry (AEC) to simplify and improve sustainability in construction works. The construction industry suffers in terms of project performance and success rate on a global and national scale due to a lack of proper planning. To solve this problem, it is necessary to adopt the use of technology in carrying out tasks in the project planning phase of a construction project. Hence, BIM is taunted to be the bridging gap needed for this purpose. This study aims to assess the benefits of implementing BIM at the project planning stage of construction projects. To achieve this, a quantitative research methodology was employed in retrieving data. Data were retrieved using a questionnaire survey distributed to professionals in the South African built environment. The data retrieved were analysed using descriptive and inferential analysis. The study revealed that the top three benefits of implementing BIM for project planning in the construction industry are: competitive advantage, saving time and money, and increasing collaboration among AEC experts. The study further clustered the variables into three components namely "productivity, efficiency, and process improvement", "information management and collaboration", and "quality, safety, and competitive advantage". The study concluded that the identified benefits of BIM implementation for project planning could serve as the drivers for its adoption among construction professionals in South Africa, considering the low adoption of BIM in the industry.

Keywords
BIM, Construction, Management, Planning, Project

1. Introduction

Before the pandemic, the construction industry employed about 7.7% of the worldwide workforce, with predictions for 2020 showing that it will generate 13.4% of global GDP (International Labour Organisation, 2021). However, the present crises facing the industry such as declining income and rising project delivery associated problems have led the industry to decline in most markets, negatively impacting the labour force, GDP, and employment figures (International Monetary Fund, 2021). The construction industry is saddled with the responsibility of delivering infrastructure projects to sustain daily human endeavours and livelihood. These infrastructure projects are executed in different phases. The Project Management Institute (PMI) outlines the five project management stages that can give a high-level perspective of the project and act as a path to completion (Pathak, 2021). These stages include initiation, planning, execution, controlling and close-out. It is this approach that project managers use to plan, monitor, and execute a project (Emuze & Mhlwa, 2015) since project management specifies the tools and procedures needed to design, plan and execute any project to bring it to a successful end (Demirkesen & Ozorhon, 2017). Review of various studies have shown that the construction industry suffers in terms of project performance and success rate on a global and national scale due to lack of proper planning (Bertelsen, 2003; Emuze & Mhlwa, 2015; Kwofie, et al., 2017; Akinradewo et al. 2022a) and thus the link between the project's success and project planning is widely acknowledged. It is then important to focus resources for change related to digitisation and sustainability in the early stages of the project management phases. According to Sakikhales & Stravoravdis, (2017) these phases have a greater impact on the project's success. In a bid to achieve improvement in these phases, various technologies with various digitalisation capabilities needs to be incorporated.

Olanrewaju et al. (2021) asserted that building information modelling (BIM) is at the forefront of technological developments, Furthermore, it may be integrated with the success method throughout the preliminary and overall phases of a project. BIM entails not only the use of dimensional intelligent models, but also major modifications to the workflow and project delivery procedures (Azhar, et al., 2012). The implementation of BIM as an umbrella for emerging technology in the construction industry in the early phases of a project will contribute to the efficiency of the adoption of digital technologies. This assumption is based on a myriad of literature (Wang & Chien, 2014; Gledson, 2016; Turka & Klincb, 2017), linking BIM with various digital technology. BIM will also increase the adoption rate for digitisation in the project planning phase as it is the most crucial phase (Sakikhales & Stravoravdis, 2017). Hence, this study is carried out to assess the benefits of adopting BIM for project planning phase in the construction industry. This research contributes to the body of knowledge by adopting a developing economy, in this case, South Africa, a context where BIM adoption is low. The study also provides a comprehensive and systematic understanding of how BIM can improve various aspects of construction project planning. The findings of the study is expected to serve as drivers for BIM adoption among construction professionals in South Africa, considering its low adoption in the industry..

2. BIM for Construction Project Planning

The current situation of the global construction sector needs continuous improvement which is advantageous to all interested parties in the pursuit for progress. This improvement measure has been characterised as innovation. In the construction business, the Building Information Model (BIM) is an example of such innovation (Odubiyi, et al., 2019). There are various benefits attached to the implementation of BIM for project planning as identified from extant literature. Studies have shown that that the solution to the fragmentation experienced among construction professionals is widely linked to the implementation of BIM (Migilinskas et al., 2013; Wang & Chien, 2014; Mehran, 2016). BIM is expected to enhance communication between project participants (Osunsanmi, et al., 2018). This will result in less effort on duplication of work, delayed communication and loss of information, less collision in project design, among others. Goedert and Meadati (2008) submitted that the difference with having digital information is the information can be queried, it is not kept static. Contrary to paper-based information where locating a specific document can be time consuming. Furthermore, BIM will transform the way construction work is organised, done, and documented, and will allow for significant improvements in the construction delivery process.

For project team members to properly gain the value from the relevant model information, BIM implementation necessitates careful planning and basic process adjustments (Messner, et al., 2019). Pilot projects can be carried out to optimise the construction sequence by various stakeholders allowing the project manager to have greater insight during the project planning stage (Kamyab, 2018). Also, by assisting architects, engineers, and other project participants in merging their models, identifying interdependencies and conflicts, and swiftly evaluating design iterations, BIM improves design and engineering processes and promotes their parallelisation. Simultaneously, increasing the quality of the final product (Gerbert, et al., 2016). Also, meeting performance criteria becomes difficult and costly if sustainability analysis is not performed early in the project planning phase. Sustainability and performance analyses may be performed throughout the design process by utilizing BIM technology with the objective is and the utilization of recycled resources (Bertin, et al., 2020). Furthermore, it can be deduced that implementing BIM during the planning stage presents the opportunity to utilise all BIM dimensions further enhancing interoperability amongst the industry and an eventual increase in the level of maturity from the users involved (Mahajan, 2018). To operationalise the benefits to the implementation of building information modelling for project planning, Table 1 itemises the identified benefits reviewed and their sources.

Table 1. Benefits of BIM for Project Planning.

S/N	Identified Benefits	Authors
1.	Collaboration	Migilinskas et al. (2013); Wang & Chien (2014); Mehran (2016)
2.	Less documentation	Goedert & Meadati (2008); Turka & Klincb (2017)
3.	Reduced documentation	Kamyab (2018); Messner et al. (2019)
4.	Improved quality	Gerbert et al. (2016)
5.	Improved health and safety	Ganah & John (2017)
6.	Increased sustainability	Bertin et al. (2020)
7.	Time and cost saving	Gerbert et al. (2016)

8.	Competitive edge	Gerbert et al. (2016); Awwad, Shibani & Ghostin (2020)
9.	Catalyst for digitalisation	Mahajan (2018)
10.	Project visualisation through 3D models	Akinradewo et al. (2021)
11.	Collaborative project delivery method	Adekunle et al. (2022)
12.	Improved investor influx	Wang & Chen (2014)
13.	Improved communication	Chan, Olawumi & Ho (2019)
14.	Project simulation	Kamyab (2018)
15	Boosts investor's confidence	Chan, Olawumi & Ho (2019); World Bank Group (2021)

3. Research Methodology

The rationale of the current study is to contribute to the body of knowledge on the benefits of BIM implementation in the planning phase of the construction project. To achieve this, the study adopted the quantitative research approach. A quantitative research method is useful in getting information from a sample of people and reporting on the questions posed by the researcher. When conducting a study that makes use of quantitative research, the numerical measurement of specific aspects of phenomena is imperative and should be precise. The study retrieved data through a structured questionnaire which was distributed to respondents which includes architects, construction managers, engineers, project managers, and quantity surveyors in the Gauteng province, South Africa.

A 5-point Likert scale questionnaire was developed using information obtained from reviewed literature with the questionnaire survey divided into two sections. The first section extracted information about the respondents' demographics in which three questions were asked. The second section focused on the identified latent variables to measure the benefits. The choice of Gauteng province was because it houses the majority of the professionals within the country who are adopting modern technologies for construction activities. About 6450 built environment professionals has been identified across Gauteng province but all of them cannot be adopted for the study due to time and cost constraints. 189 questionnaires were randomly distributed to professionals within the study area between September and November 2022, and 167 questionnaires were recovered totalling 83% response rate. All the questionnaires recovered were deemed to be suitable after being reviewed for completion. The data obtained from the questionnaire were evaluated using the Mean Item Score (MIS) and Standard Deviation (SD). Cronbach's alpha was adopted to determine the reliability coefficient of the data collection instrument. The adopted cutoff alpha for this study was 0.70, and the analysis result indicated 0.93 making all data retrieved reliable.

4. Findings and Discussions

According to the findings from the analysis conducted, majority of the respondents who were contacted and responded to the survey work at a consultancy firm with the data indicating a total of 48% while professionals working with contracting firm are 28% of the population sample. Also, tertiary students who are working and studying concurrently and government employees both make up 12% each. The most common qualification among respondents was the bachelor's degree (32%). In second place were Bachelor Honour's degree (28%) and Diploma (28%). Highest qualification possessed by the respondents was the master's degree (12%). An overwhelming majority of the respondents have worked for 0-3 years (60%), this indicates that the population sample is quite young in the industry, followed by 4-8years of experience (28%) while 8% of the sample has 9-15 years of experience. Only 4% of the respondents have worked for more than 15 years. This is an indication that the respondents possess above average knowledge to provide tangible answers to the research question.

4.1 Descriptive Analysis: Benefits of the Implementation of BIM for Project Planning

Based on the opinion of the respondents, the benefits of using BIM for project planning are summarized in Table 2. The highest ranked benefit is 'Gives a competitive edge' (MIS=4.56, SD=0.651), while 'Time and cost saving' ranked joint second (MIS=4.48, SD=0.714) with 'Increases collaboration' (MIS=4.48, SD=0.653). at the bottom of the ranking were 'Less documentation required' (MIS=4.04, SD=1.172) and 'Elimination of wastage' (MIS=4.04, SD=1.098) both ranked thirteenth while 'Boosts investor's confidence' (MIS=3.52, SD=1.418) ranked fifteenth and lowest. However, it was noted that all the variables had mean item scores above 3.00 which is adjudged the median for a 5-point Likert scale. Hence, it can be presented that the respondents agree that the identified benefits are applicable to BIM usage in the project planning stage. The standard deviation values in the table describe the amount of variability or spread in the responses received for each benefit of implementing BIM for project planning. The higher the standard deviation value, the more dispersed the responses were around the mean score. Looking at the table, it can be observed that the benefits with lower standard deviation values, such as “Gives a competitive edge,” “Increases collaboration amongst AEC professionals,” and “Improves quality of work,” had more consistent ratings among the respondents. On the other hand, benefits with higher standard deviation values, such as “Less documentation required,” “Elimination of wastage,” and “Boosts investor's confidence,” had more variability in the ratings, indicating that some respondents had significantly different views about the importance or effectiveness of these benefits compared to others. This can be attributed to their professional affiliation which determines how they perceive BIM and the identified benefits of it.

Table 2. Descriptive analysis result of benefits of the implementation of BIM for project planning.

Benefits	Mean Item Score	Std. Deviation	Rank
Gives a competitive edge	4.56	0.651	1
Time and Cost Saving	4.48	0.714	2
Increases collaboration amongst AEC professionals	4.48	0.653	2
On-site real time simulation	4.40	0.816	4
Better communication through enhanced quality information	4.36	0.810	5
Improves quality of work	4.36	0.638	5
Improves health and safety on site	4.24	0.831	7
Visualisation of project details through 3D models	4.24	1.052	7
Clash detection	4.24	0.879	7
Increases productivity	4.20	0.866	10
Provoking shift to a collaborative project delivery method	4.16	1.143	11
Increases rate of digitalisation in the construction industry	4.08	0.997	12
Less documentation required	4.04	1.172	13
Elimination of wastage	4.04	1.098	13
Boosts investor’s confidence	3.52	1.418	15

4.2 Exploratory Factor Analysis: Benefits of the Implementation of BIM for Project Planning

Further to the descriptive analysis carried out on the retrieved data, exploratory factor analysis was done. Table 3 presents the results of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The KMO measure is 0.897, indicating that the data is generally suitable for factor analysis. Bartlett's test statistic is approximately 974.113 with 101 degrees of freedom, and the p-value is less than 0.001, which indicates that the correlations among the variables are sufficiently different from zero to justify factor analysis. Overall, the results suggest that the data is suitable for factor analysis, and there are likely to be underlying factors that can explain the patterns of correlation among the observed variables.

Table 3. KMO and Bartlett's Test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.897
Bartlett's Test of Sphericity	Approx. Chi-Square	974.113
	df	101
	Sig.	0.000

The table presents the communalities of the benefits of implementing Building Information Modelling (BIM) for project planning. Communalities are measures of the proportion of variance in each variable that is explained by the underlying factors extracted through principal component analysis. The values range from 0 to 1, with higher values indicating that the variable is more strongly associated with the underlying factor. In this case, all variables have an initial communalities value of 1.000, which indicates that each variable is perfectly correlated with itself. After extraction through principal component analysis, the communalities values range from 0.601 to 0.833, indicating that each variable is associated with one or more underlying factors. Overall, the communalities values provide information on the strength of the relationship between each variable and the underlying factors extracted through principal component analysis, and can be used to interpret the results of factor analysis.

Table 4. Communalities of benefits of the implementation of BIM for project planning.

	Initial	Extraction
Increases productivity	1.000	0.632
Time and Cost Saving	1.000	0.833
Less documentation required	1.000	0.815
On site “real time” simulation	1.000	0.631
Increases rate of digitalisation in the construction industry	1.000	0.710
Improves quality of work	1.000	0.615
Gives a competitive edge	1.000	0.683
Visualisation of project details through 3D models	1.000	0.715
Clash detection	1.000	0.712
Increases collaboration amongst AEC professionals	1.000	0.667
Provoking shift to a collaborative project delivery method	1.000	0.785
Elimination of wastage	1.000	0.623
Improves health and safety on site	1.000	0.635
Better communication through enhanced quality information	1.000	0.601
Boosts investor’s confidence	1.000	0.684
Extraction Method: Principal Component Analysis.		

The variance of the components was extracted, and it was discovered that the first component has the highest initial and extraction sums of squared loadings, explaining 48.697% of the variance with eigen value of 7.305 in the data. The second and third components also have relatively high extraction sums of squared loadings, explaining 10.033% and 6.915% of the variance together with 1.505 and 1.037 eigen values, respectively. The remaining components explained less than 6% of the variance each. Hence, the three components were extracted as evident from the Scree plot shown in Figure 1.

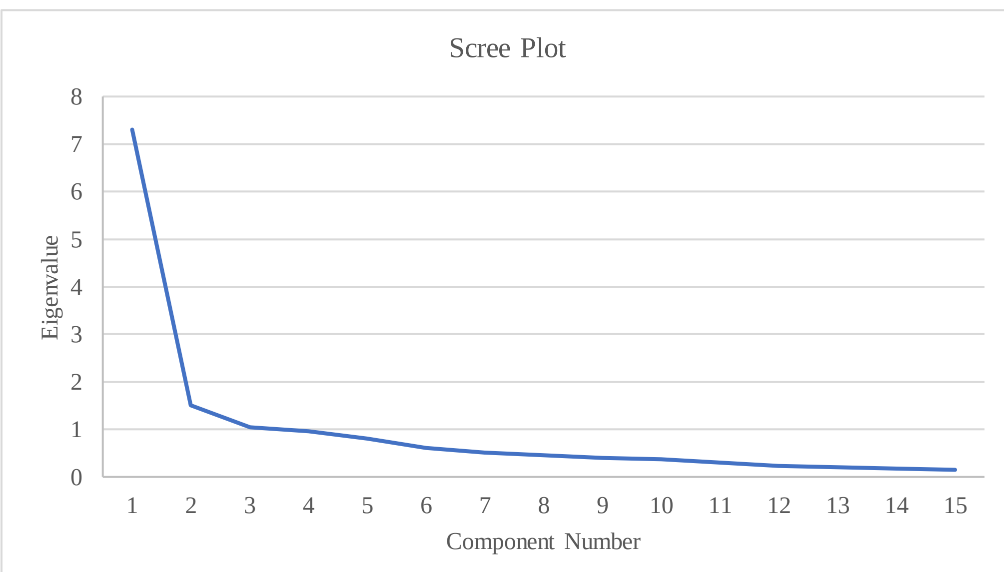

Fig. 1. Scree plot for benefits of the implementation of BIM for project planning.

The table presents the pattern matrix for benefits of implementing BIM for project planning. The pattern matrix shows the correlations between the observed variables and the underlying factors extracted through principal component analysis. In this case, three components were extracted, and the correlations between each variable and each component are displayed in the table. Variables with high correlation coefficients (0.7 or higher) with a particular component are considered to be strongly associated with that component. Variables with low correlation coefficients (less than 0.3) with all components are considered to be weakly associated with the underlying factors extracted through principal component analysis. The three components extracted in the pattern matrix provide a deeper understanding of the underlying factors that explain the correlations between the benefits of implementing BIM for project planning in South Africa.

Component 1 includes variables that are strongly related to productivity, efficiency, and process improvement. “Increases productivity”, “Time and Cost Saving”, “Less documentation required”, and “On-site real-time simulation” are all highly correlated with Component 1. This suggests that BIM implementation can lead to significant improvements in productivity and efficiency by reducing documentation requirements, facilitating real-time simulations, and reducing costs and time associated with construction projects (Akinradewo et al., 2021).

Component 2 includes variables related to information management and collaboration. “Increases rate of digitalisation in the construction industry”, “Increases collaboration amongst AEC professionals”, “Provoking shift to a collaborative project delivery method”, and “Better communication through enhanced quality information” are all highly correlated with Component 2. This suggests that BIM implementation can lead to better information management and collaboration among different stakeholders in construction projects, resulting in more efficient and effective decision-making and project delivery (Adekunle et al., 2022).

Component 3 includes variables related to quality, safety, and competitive advantage. “Improves quality of work”, “Gives a competitive edge”, “Improves health and safety on-site”, and “Boosts investor's confidence” are all highly correlated with Component 3. This suggests that BIM implementation can lead to improvements in the quality of work, better safety on-site, and increased confidence among investors (Akinradewo et al., 2021; Adekunle et al., 2022). Moreover, BIM can provide a competitive advantage to construction companies by enabling them to deliver high-quality projects more efficiently and cost-effectively than their competitors (Awwad, et al., 2020).

Overall, the three components extracted from the pattern matrix provide a comprehensive view of the benefits of implementing BIM for project planning in construction projects. Understanding these underlying factors can help stakeholders to identify the areas where BIM can provide the most significant benefits and develop strategies to optimize its use in construction projects.

Table 5. Pattern Matrix for benefits of the implementation of BIM for project planning.

	Component		
	1	2	3
Increases productivity	0.933		
Time and Cost Saving	0.910		
Less documentation required	0.865		
On site “real time” simulation	0.802		
Visualisation of project details through 3D models	0.728		
Clash detection	0.676		
Elimination of wastage	0.610		
Better communication through enhanced quality information	0.548		
Increases rate of digitalisation in the construction industry		0.944	
Increases collaboration amongst AEC professionals		0.714	
Provoking shift to a collaborative project delivery method		0.625	
Improves quality of work			0.904
Gives a competitive edge			0.833
Improves health and safety on site			0.781
Boosts investor’s confidence			0.624

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
a. Rotation converged in 8Dis iterations.

The adoption of BIM has given companies in the United Kingdom a competitive edge (Awwad, et al., 2020). These findings affirm the opinion of the respondents that the adoption of BIM for project planning will give companies a competitive edge. In the same vein, Wang and Chien, (2014) asserted that BIM will reduce costs and time. However, the improvement of collaboration among professionals was ranked third by the respondents. Migilinskas, et al., (2013) stated that collaboration is key to the usage of BIM. Hence, these findings are aligned with seminal literature. Less documentation required, elimination of wastage and boosting of investor's confidence were the three least ranked benefits by the respondents. In contradiction, Azhar, et al., (2012) reported that cost savings emanating from the reduction of printing costs due to the usage of BIM has aided in the elimination of waste. This suggest that these benefits are not witnessed by the sample or could be an indication of the low usage of BIM currently in South Africa as reported by Akinradewo et al. (2022b).

5. Conclusions and Recommendations

This study was set out to assess the benefits of BIM implementation at project planning stage in the construction industry using South Africa as a focus. The common benefit identified in the literature review was that BIM is a solution to the fragmentation that plagues the industry. Often, this fragmentation has birthed a myriad of problems in the industry. Other benefits identified include but not limited to improved quality of work, less documentation required and the fact that a BIM offers a competitive edge to the companies that adopt it. The study adopted a quantitative research methodology such that data were retrieved from professionals in the South African construction industry using a questionnaire survey. Based on the descriptive and exploratory analysis conducted, it can be concluded that the implementation of Building Information Modelling (BIM) in project planning has numerous benefits for the architecture, engineering, and construction (AEC) industry in South Africa. The highest ranked benefit identified by respondents was that BIM gives a competitive edge, followed closely by time and cost savings and increased collaboration among AEC professionals. While some benefits, such as less documentation required and elimination of wastage, were ranked lower, all identified benefits had mean item scores above 3.00 on a 5-point Likert scale. Exploratory factor analysis indicated that the benefits of BIM implementation can be grouped into three components: productivity, efficiency, and process improvement; collaboration and communication; and design and visualization. The findings suggest that BIM implementation can lead to significant improvements in productivity, efficiency, collaboration, and cost savings in the AEC industry in South Africa. This study concluded that the construction industry will benefit immensely from the early adoption of BIM for project planning. This is expected to promote project performance and efficiency in the construction industry. It was therefore recommended that architectural, engineering and construction professionals incorporate BIM into their construction project planning phase. The study was limited to professionals in Gauteng province of South Africa only. Hence, further study should be carried out using all the professionals from across South Africa to have a more general opinion of professionals.

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An Overview of BIM as a Material Management Tool in the Construction Industry

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Abstract

The construction industry's acceptance of innovative technological tools such as Building Information Modelling (BIM) is rapidly increasing globally. Based on scholars' findings, BIM has shown substantial capability in the building project's whole lifecycle. The construction stage entails a series of managerial tasks. Material management is one of the crucial notable managerial tasks performed during the construction phase of a project. For decades building materials management has solely relied on manual managing and recording. These usually resulted in increased construction costs and waste of materials. These challenges have raised great concern for the construction manager (CM). The CM is now looking for an innovative way of managing building materials. This study aims to check the capacity of BIM as a material management tool based on the available results. Secondary data sources were thoroughly evaluated, and trends and visualization network mapping were carried out. The findings of this study disclose that the BIM-based material management model can help minimize rebar waste and effectively manage material handling and supply during construction. This study will create more awareness of BIM capability. These will alert the construction managers and BIM experts to consider BIM adoption in managing building materials. Also, add to the knowledge on building material management based on an innovative technology approach. Subsequently, it will increase the adoption and wider use of BIM in the construction stage.

Keywords

BIM, Material Management, On-site, Construction Manager, Innovative.

1. Introduction

The construction industry is regarded as one of the largest global project-based sectors. It primarily expected the completion of projects within budget and on schedule. Understanding the proper handling and management of materials becomes an essential on-site task. Odubiyi et al. (2021) noted that achieving a construction project's success requires effective materials management. Proper materials management during construction can reduce the project delay time. Moreover, several studies have identified the lack of appropriate material and resource management as part of the critical challenges construction projects suffer (Kasim et al., 2021; Mall, 2019; Na et al., 2021; Odubiyi et al., 2021; Wu, 2020).

Material management is a process that coordinates sourcing, planning, purchasing, storing, analysing requirements, minimising waste, transporting, and regulating resources, and improving profitability by reducing material costs (Patel & Vyas, 2011). Although, Manual recording and management of building materials have been the only option in the construction industry for decades. These often resulted in higher building costs and resource waste. Abou-Ibrahim et al. (2019) opined that 50% - 60% are the costs associated with costs incurred from improper on-site material management. These could result in an 80% delay in several construction projects (Caldas et al., 2015). With the current evolution of innovative technologies in the construction industry globally. The industry is now rapidly trying to adopt an innovative model that could enhance the management of materials needed/used during building production (Beorkrem, 2015; Čuš-Babič et al., 2014). One of the adopted models is Building Information Modelling (BIM).

Nevertheless, the adoption and integration of BIM in the conception/design and construction stage of building projects have gained significant attention, mostly in developed countries (Ullah et al., 2019; Wang & Wang, 2015). Its adoption at the post-construction stage is still at the infant stage (Toyin & Mewomo, 2022). Nevertheless, BIM adoption to manage the coordination of the material flow process has not received significant attention. Researchers such as (Chen et al., 2020; Čuš-Babič et al., 2014; Mostafa & Zhineng, 2018; Wu, 2021), etc. have tried to contribute substantially to this context. However, there are limited or no comprehensive available records that triangulate the finding of several scholars on the use of BIM for material management. Therefore, this study seeks to juxtapose the available findings of researchers and experts in this study area by conducting an extensive review of published documents supported by trends and visualisation network mapping. With a focus on BIM use for material management during construction invented.

2. Study Methodology.

It is essential to define precise boundaries in a literature review to restrict the study (Toyin & Mewomo, 2023). The articles considered for this study were sourced from Google Scholar, Scopus, and Web of Science (WOS). The adopted sourced search engines and database was considered because they are one of the largest scientific databases and search engine; They possess a high degree of quality control and cover a wide range of research disciplines (Mewomo et al., 2021; Ullah et al., 2019). Google Scholar was used to locate links to related materials in their repository domain. This study follows three distinct steps, as depicted in Figure 1. The first step entails data sourcing. In the retrieval of relevant articles for this study, the following keywords and phrases were repeated in the selected databases and search engines: "BIM" OR "Building Information Model*" AND "Material Manage*" within "Article Title/ Abstract/ Keywords." The use of '*' in the search keywords allows a broader range of locating articles with different spelling strings of a suffix, such as model*: - Model, Modeling, Modelling, etc. The retrieved documents were restricted to journal articles, conference proceedings, and book chapters written in English (Toyin & Mewomo, 2021). Google Scholar search generated 21 documents, Scopus generated 20 documents, and WOS generated six documents. Thus, an initial total of 47 documents. The 47 documents were then imported into an excel spreadsheet as a CSV file for screening and filtration. Hence, 26 duplicates were deleted, left with 21.

Further abstract screening was conducted, eliminating an additional document on rail infrastructure. Thus, finally, n=20 articles. Step 2 involves an extensive overview and visualization of the retrieved articles to deal with the aims and objectives of this study. Overview in research could be seen as a flow process where researchers bring together several contributions of scholars in tandem with the study context. Finally, Step 3 covers the conclusions and suggestions for further study.

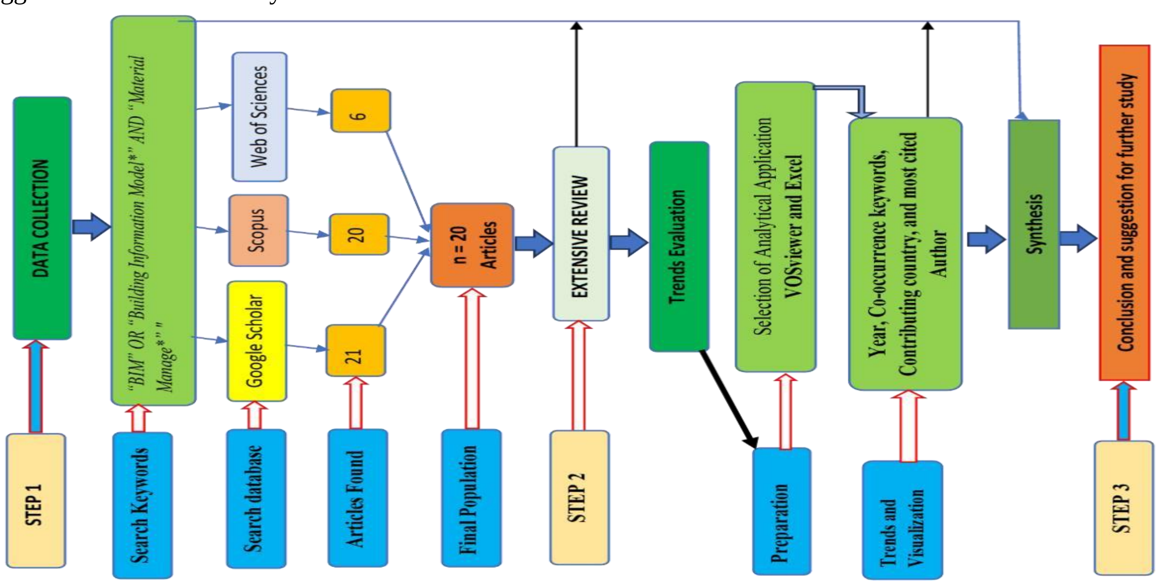

Fig. 1. Study flows sequential flow chat.

Fig. 2. Data location.

3. Extensive Overview discussion

3. 1 Material management using BIM-Model

There would be no comprehensive discussion of material management in the construction industry if the essential components of material management were not mentioned. According to (Gulghane & Khandve, 2015; Kulkarni et al., 2017), Materials management can be categorised into five processes. These are majorly found on construction sites: "Planning, Procurement, Logistics, Handling, and Stock and waste control" processes. Materials planning includes quantifying, ordering, and scheduling (Albert et al., 2018). Figure 3 explains the five processes in a schematic chat.

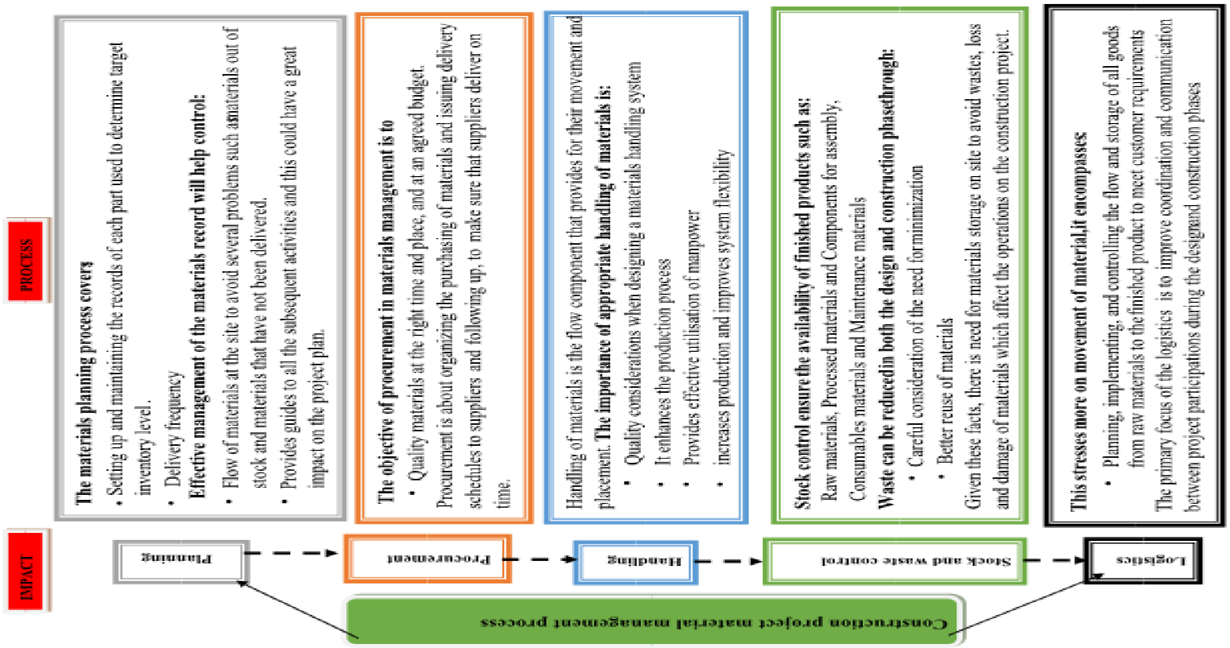

Fig. 3. Construction material management process.

Nevertheless, the management of building materials is an incorporated procedure that contains the integration of technology, organizations, people, and procedures. It is used to acquire effectively, quantify, expedite, identify, inspect, store, receive, transport, and conserve the equipment, materials, and related information throughout the lifecycle of a capital project (Caldas et al., 2015). However, the primary aim is to guarantee that the correct quantity and quality of equipment and materials are acquired efficiently, purchased at a realistic cost, and available when needed. Nevertheless, adopting innovative managerial models such as BIM for material management will contribute to more successful project results (Wei et al., 2017). BIM could improve quality and productivity, reduce costs, and enable a better working environment (Ma, 2018). Moreover, this could be achieved through using reliable, innovative material management techniques in construction projects—Table 1 documents the authors' main objective for conducting their research and the contributing findings.

Table 1. Author's contribution to material management using BIM.

Purpose	Contribution
(Porwal & Hewage, 2012)	
The author proposed a model to analyze reinforced concrete structures using the waste-optimization technique integrated with BIM.	Minimize rebar waste during the design stage and supports cost-effective decision-making during the design process
(Čuš-Babič et al., 2014)	
The author proposed a BIM theoretical model for information mapping concerning material management. They used a construction company's operational environment as a case study.	The researcher presented an approach that supports the mapping model and documents the benefits accruable by the industry.
(Wang & Wang, 2015)	
Application of the BIM-based Model to resolve problems emanating from green building materials management (GBMM) with the combination of life cycle assessment theory.	The management of the materials was framed on BIM-Model. It improves the management level of GBM in the construction project.
(Feng & Lin, 2017)	
Proposed a framework for the BIM Model to manage MEP materials in construction projects.	The model enhances information transmission and efficiency of the MEP professional and achieves the purpose of cost control
(Wei et al., 2017)	
Investigate using a BIM-based Model for calculating auxiliary materials needed for building construction.	The proposed model significantly enhances auxiliary materials management and the supervision of material distribution.
(Ma, 2018)	

Purpose	Contribution
Studies the management of green building materials and develops a BIM-based material management evaluation model.	The authors submit that the BIM-based model and supply chain systems could deliver supply chain information fast, accurately, and safely
(Mostafa & Zhineng, 2018)	
Study the integration of the BIM-Based model in green building materials management.	The scholar triangulates the need to improve China's current means of managing green building materials with BIM adoption.
(Mall, 2019)	
Investigate the application of BIM to reduce material waste	Design a model for BIM waste reduction.
(Wu, 2020)	
Compare the use of BIM for material management with the conventional method.	Used sampling survey and sand table simulation technology to conduct the investigation.
(Beorkrem, 2015)	
Assess the suitability of BIM for Material management and fabrication.	Implement BIM-model to embrace the management of materials and fabrication.
(Yu et al., 2016)	
Investigated the use of a BIM-based model for managing the supply of site materials	They developed a dynamic BIM-based model for managing the supply of site materials.
(Hu et al., 2021)	
The author investigated the application of BIM technology to manage a stadium project.	Use of a BIM-based model for managing material during stadium construction.

3.2 BIM integration as a material management tool.

Porwal and Hewage (2012) designed an innovative methodology in the Canadian Architecture, Engineers, and Construction (AEC) industry, to minimize rebar waste during the project design stage. Through analyses of BIM models with a quick optimization technique. This technique allows project stakeholders to use BIM models to "simulate relevant project design requirements" and compare results faster to effect necessary design adjustments to reduce rebar waste. Čuš-Babič et al. (2014) Investigate the issues related to the integration of information flow in the construction industry supply chain. The authors focused on a case study using a BIM-based Model for material management. Their findings proposed how to bridge gaps among the information systems used for on-site construction material management processes. The scholars submit that integrating the BIM-based model in construction can minimize issues resulting from improper material management and information gaps. The study of (Wang & Wang, 2015) investigated the combination of BIM and Radio Frequency Identification (RFID) technology to improve the management level of green building materials. The findings reveal that implementing these techniques improved the management level of green building materials compared with non-BIM and RFID-based projects. Fig. 2 shows the design framework for material management. The researchers see RFID as a "non-contact automatic identification technology, which is usually used for data collection." At the same time, BIM serves as an information exchange model that saves scanned data and information collected by RFID in the design process to visualize green building components, materials, and construction projects.

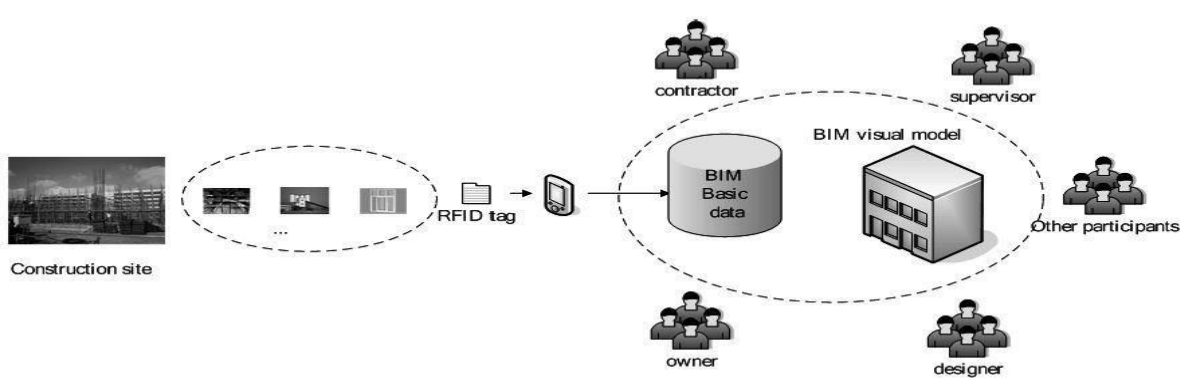

Fig. 4. BIM and RFID material implementation system framework. (Wang and Wang, 2015).

The study of Feng and Lin (2017) focused on how to use the BIM model to smoothen the management of MEP materials, focusing on a case study of fire-fighting systems. Dynamo modules were formed to smoothen the process of developing the BIM model for the case study. The findings of Mall (2019) identified the causes of material waste on construction sites and the problem faced by its management. The adoption of BIM for material management was demonstrated to eliminate most problems. The author designed a BIM-based model to arrest those problems. The model's outcome summarized it could reduce clashes that could lead to material waste during construction, coordinate design to reduce waste on-site, and reduce redesign and rework, which could lead to material waste. Wu (2020) uses the method of "sampling survey and sand table simulation technology to compare the prefabricated building material management based on BIM technology with the conventional method" it focuses on the production and construction stages. The result reveals that adopting BIM in managing building materials has an advantage over the traditional method.

Beorkrem (2015) noted the need for BIM in managing building materials due to the unique nature of the design material. It was noted that BIM could be utilized as a design and production tool that integrates ethical and inventive decision-making within parametric design environments. Thus, it can help improve its management during the construction phase. Figure 5 shows the BIM model's line used for building materials management.

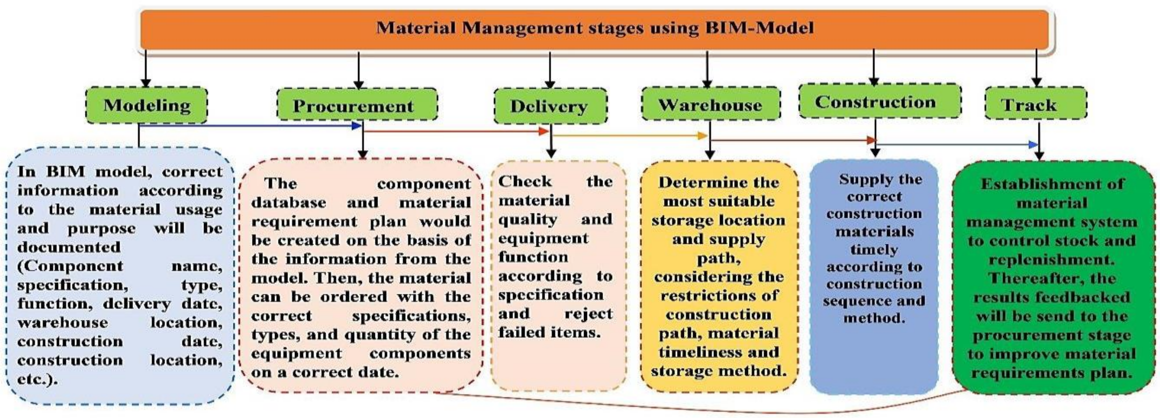

Fig. 5. Use of BIM-model to manage building materials.

Wei et al. (2017) proposed a BIM-based model for effectively managing auxiliary materials needed for building construction. The authors found that the developed model is more effective and consistent in managing and calculating the number of auxiliary materials needed for the project compared to the previous management process. These significantly reduced auxiliary materials waste and strengthened supervision in material distribution. The study of Ma (2018) focused on using a theoretical basis for applying a BIM-based model in the green building materials management system. A logical structure for managing green building materials was developed based on BIM. According to the authors, BIM may increase information cooperation and database sharing. Project parties can optimise and supplement the information in a timely way, decreasing information loss and management expenses. Mostafa and Zhineng (2018) researched in China, where there has been a report on the imperfect status of the China green building material management (GBMM) system. Therefore, the authors proposed using BIM technology to improve the management of the GBMM system. RFID was also incorporated for monitoring and tracking the management of construction materials.

To automate the input of information in the BIM model. The study by Yu et al. (2016) proposed a BIM-based model for managing materials supplied to the site. The authors validated the model by subjecting it to a real-life case study. The BIM-based model demonstrated its capability in managing dynamic site material through 4D modelling, optimal scheme generation method, and acquisition method of site information. Hu et al. (2021) researched the construction of a stadium; the author introduced the application of BIM-based technology in the management of stadium projects. The BIM-based model was used to monitor and manage the A-Z of the project. The application of the BIM-based model enables easy means of controlling the system progress, tracking the materials system, and safety monitoring system.

4. Trends and Visualization Evaluation

4.1 Publication per year.

Out of the over 900,000 BIM-related publications searchable in Google Scholar and over 24,000 are indexed in Scopus, and over 15,000 in WOS (Web of Sciences). Only 20 articles could be located at the time of this study

(August_9_2022) that address the use of BIM for material management. This shows that concentration in this study area is significantly low. The following can be deduced in Figure 6: The spread of the publications; in 2012, the first released article was published by (Porwal & Hewage, 2012); in the year 2020, four articles were published, which account for 20% of the total publications in this study area.

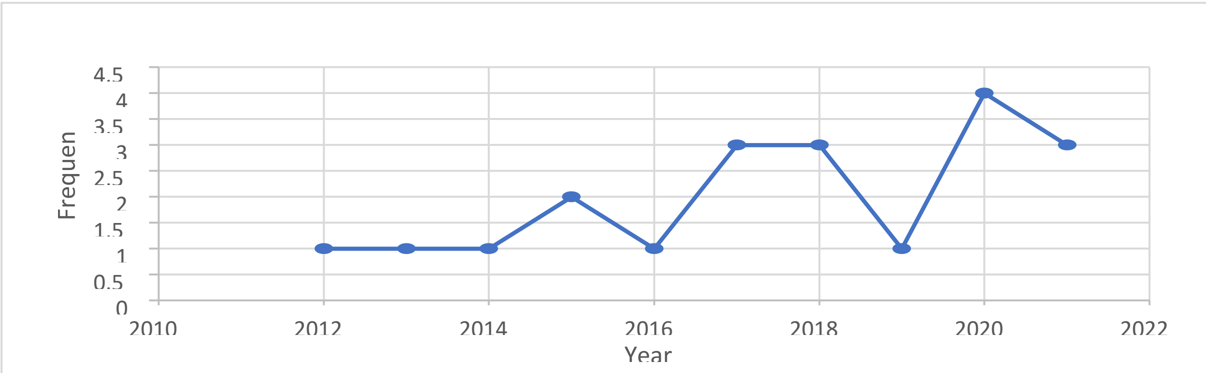

Fig. 6. Trend of publication.

4.2 Publication per year.

Keywords are phrases, nouns, and terms that comprise the essential elements of an article/publication and demonstrate the progression of study themes through time (Xiang et al., 2017). The Scopus database contains two types of keywords: (i) author keywords, which authors submit, and (ii) index keywords, which are recognized by journals. A network of co-occurring keywords was constructed with both types of keywords from the 20 bibliometrics data. Cooccurrence may also include keywords connected to the same issue but do not have the same meaning; the proximity of keywords is related to the degree of co-occurrence (Xiang et al., 2017). Initially, 215 keywords were identified. To identify the one that has occurred more than once. Inclusion criteria were set to two. Wherein 37 keywords meet this threshold. Thus, proceed to map out its overlay visualization. Overlay visualization is used to picture the occurrence trends of keywords over a period. Figure 7 shows the trends of the keywords over time. Earlier, the focus was more on waste management and material management. Then it moved to information requirements and interactive devices. However, recently the focus started from architectural design, green building materials, and BIM technology to material handling, building materials, information management, and construction management. For easy tracking of the occurrence trend, the ledged in Figure 7 shows the colour used to represent the trend move. Purple represents the initial focus, and yellow regions show the recent focus.

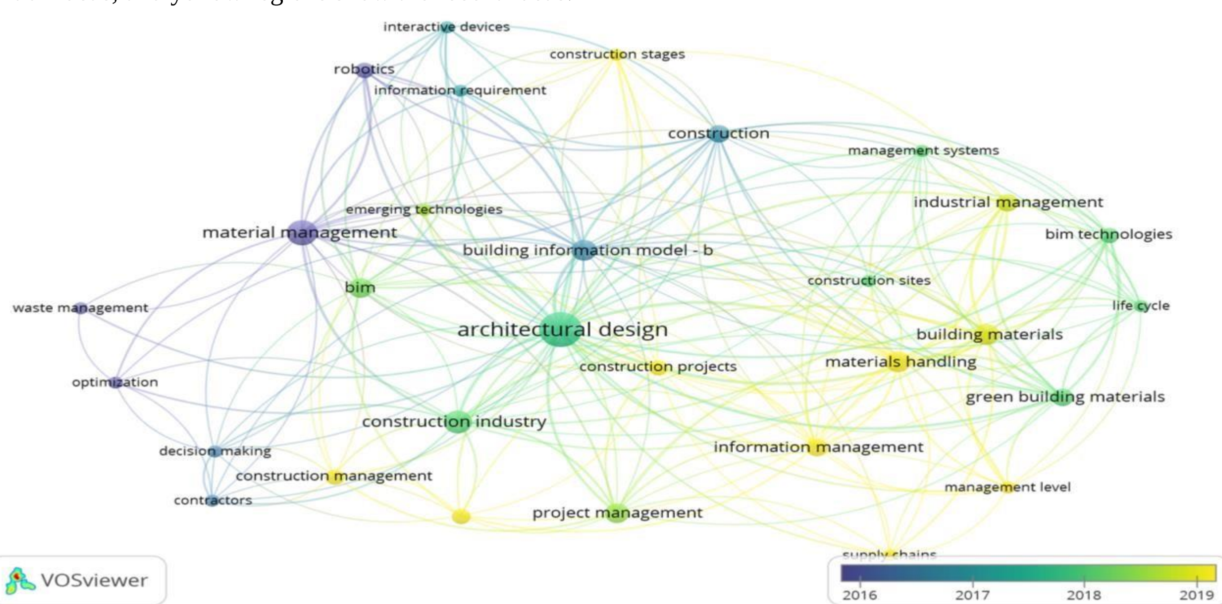

Fig. 7. Keyword trend visualization.

4.3 Publication per year.

This section outlines the most contributing countries in this study area and the most cited country at the time of this study. Seven countries have contributed to this study area. The following can be found in Figure 8: China is presently seen as the most contributing country with nine documents which account for 45% of the 20 published articles, followed by Canada. Based on the most cited county, Canada topped with 133 citations, while Slovenia followed with 59 citations, down to Germany and Taiwan having two citations each. Looking at figure 9. These unleashed the leading countries with BIM adoption as recently published (UNITED-BIM, 2022). The result of the most contributing countries in this study validated the list, having China, the United States, and Germany on the list.

Create Map

Verify selected countries

Selected	Country	Documents	Citations	Total link strength
✓	canada	4	133	0
✓	china	9	33	0
✓	egypt	1	54	0
✓	germany	1	2	0
✓	slovenia	1	59	0
✓	taiwan	2	2	0
✓	united states	2	56	0

Fig. 8. Most contributing country.

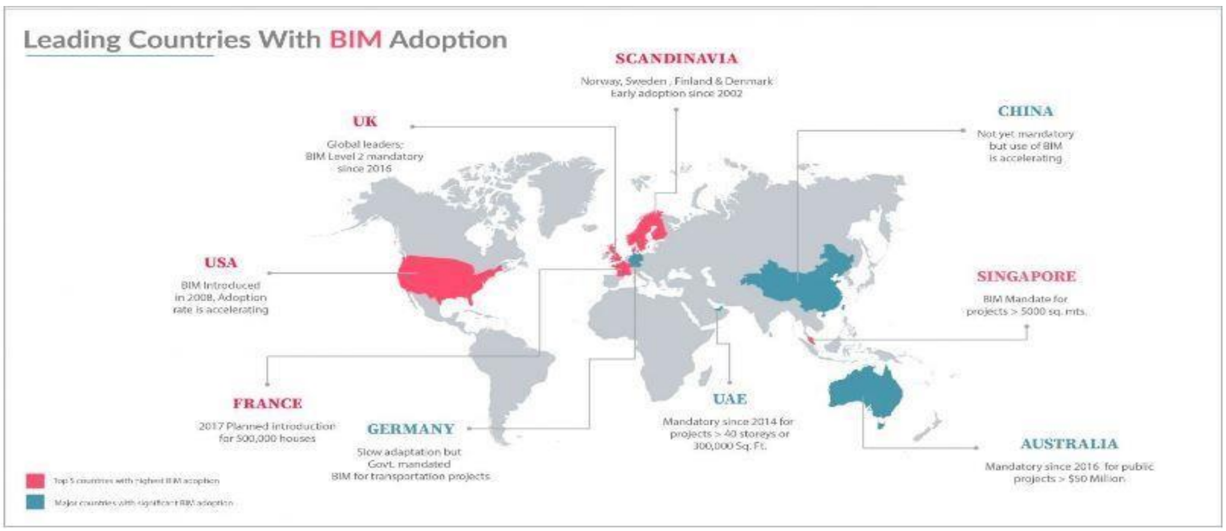

Fig. 9. Most BIM-adopted countries.

4.4 Most Cited authors.

Most cited authors' mapping is used to express various authors' significant impact and contribution to a particular study area with their publication(s). Initially, fifty authors were identified in the documents. A minimum of 50 citations was used to identify the most cited authors from the surplus of authors. Thus, eight authors meet this requirement, as seen in Figure 10. Porwal A. and Hewage K. N. had 70 citations each. This author co-authored an article titled: "Building information modelling-based analysis to minimize the waste rate of structural reinforcement."

Create Map

Verify selected authors

Selected	Author	Documents	Citations	Total link strength
✓	el-rayes k.	1	54	0
✓	hewage k.n.	1	70	0
✓	nekrep-perc m.	1	59	0
✓	podbreznik p.	1	59	0
✓	porwal a.	1	70	0
✓	rebolj d.	1	59	0
✓	said h.	1	54	0
✓	čuš-babič n.	1	59	0

Fig. 10. Most contributing author.

5. Conclusions and Suggestions for future studies.

5.1 Conclusion.

This paper presents the result of the extensive review and the visualization trend check on the status of BIM adoption for on-site building material management within the construction industry. The review findings extracted from the selected articles reveal that the implementation of the BIM model for the management of building materials during the construction phase has gained considerable attention in the following areas: “Rebar waste control, MEP material management, application of BIM technology for the management of green building materials, use of BIM to control material waste, and development of several BIM-model to assist in the management of building materials.” The visualization trend checks reveal the limited contributing authors, counties, and focus trends over the years. This shows less advancement in the adoption of BIM for material management globally. Having just seven contributing countries in this study shows that their adoption of material management is still relatively low compared to the design and procurement stage. Nevertheless, BIM is a promising and emerging innovative technology capable of solely managing building materials and can house the incorporation of other related technologies.

5.2 Suggestions for Future Studies.

There is still much research that must be conducted in the context of BIM-based technology use for the management of construction materials. Moreover, its suitability for the management of materials has been established. Therefore, researchers may:

- Validate or modify the existing BIM-Based model through a real-life case study and document the various challenges faced during the validation of the model
- Develop a BIM-based model that will incorporate the management of material and supply chains.
- Document the possible barriers hindering BIM-Based material management model implementation.

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Post-COVID-19 BIM adoption, Challenges and Perspectives among AEC firms in Africa: Case of Morocco

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Abstract
The COVID-19 pandemic emphasized the remote potential of Building Information Modeling (BIM) to enable Architecture, Engineering, and Construction (AEC) operators to sustain work under the resulting challenging circumstances. Some studies pointed out the post-COVID-19 context of BIM use in several regions, but none in Africa. Therefore, based on a mixed-method design, this study aims to fill this research gap and provides a reference for BIM-related parameters in Africa including BIM adoption, challenges and perspectives by considering Morocco as a case study. This study disclosed that the COVID-19 occurrence fastened BIM adoption among Moroccan AEC operators by 19% and urged governmental initiatives toward BIM adoption regulation but confirmed that these are still insufficient compared to the significant identified BIM challenges. This paper confirmed that personal and government-related challenges are the most critical BIM challenges in Africa and highlighted that BIM faces 2 more considerable challenges in Morocco caused by a considerable loophole in local regulation. In this vein, the paper provides remedy actions to lessen the impacts of identified challenges and smoothen BIM adoption.

Keywords
Building Information Modeling, Architecture, Barriers, Developing countries, Africa, Regulation, Construction

1. Introduction
A recent study (Bouhmoud et al., 2022b) showed the enforced restrictive health measures to face the coronavirus disease 2019 (COVID-19) caused the African AEC industry 3 types of severe complications: Financial such as revenue losses and extra-costs due to transportation, materials and workforce shortage; Operational such as production halving and termination or postponing of new or ongoing projects; and managerial/strategic impacts namely shrinkage of construction projects and challenging adaptation of new processes and workflows. Experts believed that the construction sector could be the sector pulling economies out of the negative effects of COVID-19 (Hogan, 2020) but only if the used practices were upgraded digital and remote technologies, Information and Communications Technologies (ICTs) such as virtual reality, Building Information Modeling (BIM) and unmanned aerial vehicles (Meisels and Pendergast, 2021). In fact, Bouhmoud et al. (2022a) revealed that combining the BIM with fast-track construction approach helped revealed the big potential of BIM in keeping the construction sites on activity as well as building the needed health facilities in record durations but disclosed that African countries led behind other countries in this regard.
Moreover, Naroura (2014) highlighted that BIM helps to fasten decision-making processes and enhance projects understanding and quality by 65% and 54% respectively; optimize the workflow, including clash management and modifications, by 54%; and increase the cost control by 37%. The Hong Kong Housing Authority and Housing Department (2016) confirmed that, based on collaborative 3D models, BIM allows the AEC stakeholders to manage, store and share information in efficient and remote ways. Similarly, Ahmed and Bristow (2017) demonstrated that it allows a near real-time track of design and erection progresses with detailed daily progress reports. Elghaish and Abrishami (2020) showed that 4D BIM allows an automated multi-objective to optimize and leads to cost-saving of 22.86%. Zhang et al. (2018) proved that by using BIM model to enable 3D printer, fast-tack projects could be built in a tight time, with optimized costs

and under challenging circumstances such as large neighborhoods for destitute people in poor countries or healthcare facilities during pandemics spread. As a result, BIM technology is experiencing an upward worldwide adoption (Liu et al., 2019) with an exceptional rise during the COVID-19 crisis (Dodge Contractor Panel, 2021).
In Africa, Saka and Chan (2019) confirmed that BIM technology was lightly known and barely adopted among AEC operators. This fact was confirmed by Bouhmoud and Loudyi (2020) where, based on a comparative study, they revealed that, among the 34 identified BIM barriers worldwide, Africa straggles with further primary BIM challenges compared to the remaining continents such as inadequate infrastructure, lack of electrical power, and internet connectivity; and less advanced BIM challenges such as lack of insurance and collaboration management tools. However, in an earlier study, Bouhmoud et al. (2022b) showed that COVID-19 occurrence helped increasing BIM adoption among the AEC operators. In this vein, this study aims to investigate the post-COVID-19 BIM adoption context, including barriers and perspectives but none in Africa with Morocco as a case study and, thereby, this paper would enlighten both scholars and decision-makers about BIM adoption context in the discussed region, by responding to the following questions:

1. Has COVID-19 impacted BIM adoption? And how?
2. What are the most impactful challenges on the BIM adoption?
3. What are the future BIM perspectives?
4. What are the needed actions to overcome BIM adoption challenges?

2. Methodology

The study used an embedded mixed-method design based on three methodological instruments: survey, Systematic Literature Review (SLR), and interviews.

2.1. Survey and validation

2.1.1. Questionnaire

The questionnaire included 4 categories of questions: (1) respondents' background questions, (2) questions about COVID-19 impact on BIM adaption, (3) questions about post-COVID-19 BIM perspectives., and (4) a Likert-scale question, from 1 (Not significant) to 5 (extremely blocking) with 'I don't know' scale, was included to rank the listed challenges and open-ended questions allowing the respondents to list any possible missing challenges and give further explanations.
To build the Likert-scale question a SLR about BIM challenges was undertaken (§2.2).

2.1.2. Respondents' list:

Through a purposive sampling, the authors listed 97-targeted respondents from the different AEC industry expertise areas including architects, AEC administrations, developers, engineering firms, and academic / R&D stakeholders (Fig. 1):

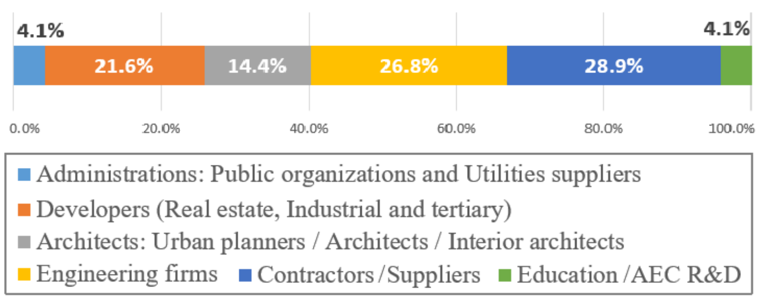

Fig. 1. Targeted respondents by areas of activity

2.1.3. Web-based and interview-based surveys

Based on the pre-designed questionnaire, a web-based survey was conducted in the first place through an emailing process. Then, an interview-based survey was conducted for the remaining targeted respondents who did not respond online. As a result, 89 feedbacks have been collected giving then a response rate of 92%.

2.1.4. Validation of the new findings:

The findings could bring out new challenges hindering BIM adoption specific to the Moroccan context. Therefore, to confirm their trustworthiness, the authors are running more substantiations by either analyzing the official data and statistics delivered by the concerned public institutions or interviewing the representative of an institution directly related to the newfound challenge.

2.2. Systematic Literature Review

A previous SLR (Bouhmoud and Loudyi, 2020) gathered all BIM challenges/barriers listed in the literature until 2020. In other to build a well-founded survey questionnaire, it was necessary to consider the data published afterward hence a complementary SLR was achieved based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach (Fig. 2).

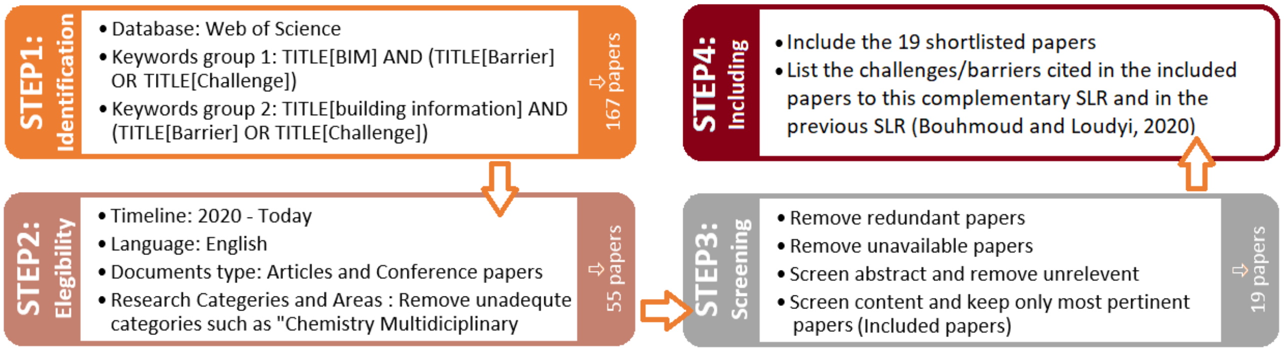

Fig. 2. workflow of the complementary conducted SLR

2.3. Interviews:

To confirm the survey's findings and collect the public perspectives toward BIM adoption, the authors interviewed five representatives of the Moroccan Ministry of National Territory Use, Town Planning, Housing and City Policy (MNTUTPHCP).

3. Findings of the SLR

The findings of the complementary SLR confirmed some of the BIM challenges disclosed by the previous SLR (Bouhmoud and Loudyi, 2020), the disparity between Africa and other continents, and the lack of studies related to BIM adoption among the Moroccan AEC firms. The main found existing BIM barriers / challenges are:

- Resistance to change, fragmentation and business culture,
- Inadequate professionals' education**,**
- High initial investment cost for BIM implementation,
- Lack of BIM standards and guidelines,
- Lack of governmental strategy for BIM adoption,
- Lack of awareness of either BIM or its added value,
- Lack of governmental incentives,
- Shortage of skilled BIM workforce and expertise,
- Lack or absence of clear contractual terms adapted to BIM use
- Lack of adequate training,
- Lack of interoperability,
- Risks related to data Security & Reliability,
- Lack of Compatibility with existing tools,
- Lack of client demand,
- Confusion of ownership and copyrights,
- Disturbance of the Workflow,
- Lack of executive Buy-in,
- Needed time for BIM implementation.

To shorten the responding time, the aforementioned challenges were combined into nine key challenges: Ch1: Lack of qualified workforce and experts in BIM, Ch2: Requirement of considerable additional budget, Ch3: Requirement of more time to both workflow adaptation and implementation, Ch4: Lack of decent trainings and academic BIM education, Ch5: Lack of regulations, standards, and guidelines, Ch6: Lack of governmental incentives and adoption strategies, Ch7: Lack of client demand and buy-in, Ch8: Resistance to change and business culture, and Ch9: Lack of BIM awareness.

4. Finding of the Surveys and Interview

4.1. Respondents' background

The respondents had diverse academic backgrounds, with civil engineers on the top with 63%, followed by architects and topographers with 14% and 10% respectively. 46% of the respondents had between 8 and 15-year experience and 44% had more than 16-year experience. Likewise, they had high job positions including CEO's position (27%) and chiefs of department / senior project directors (64%) whereas the remaining were either professors, scholars, consultants, or projects managers (Fig. 3). As shown in Fig. 4, the respondents represented engineering firms, contractors/suppliers, and developers at the percentages of 29%, 25% and 24% respectively. Architectural firms represented 17% of represented institutions and the remaining 5% gathered administrations and academic institutions (Education / AEC R&D). For the institutions' size, 71% of them had more than 500 employees and 25% had 51-100 employees.

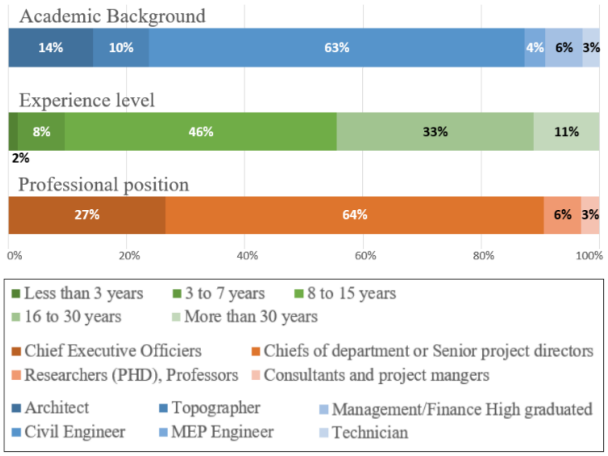

Fig. 1: Respondents' background

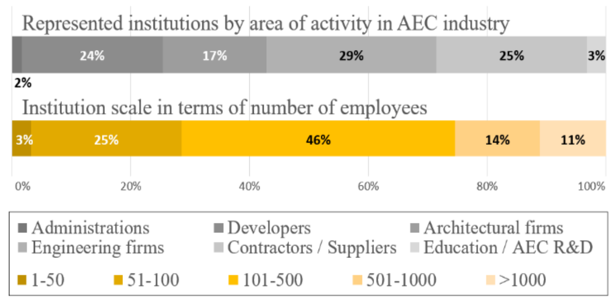

Fig. 2: Represented institutions' background

4.2. Impact weight of COVID-19 on BIM adoption in Morocco

To measure this metric, the respondents were asked to disclose their vision of BIM adoption before and after COVID-19 occurrence. The comparison (Fig. 5) showed that the respondents that were not planning to adopt BIM decreased by 19% due to the pandemic. Similarly, the rate of respondents who were planning to adopt it and those who were having BIM adoption in progress increased by 13% and 6% respectively.

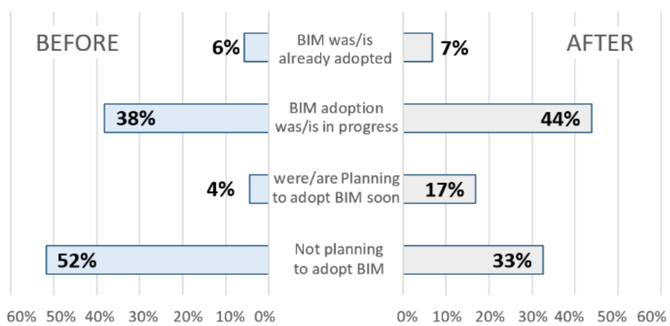

Fig. 3: BIM adoption before and after COVID-19 occurrence

4.3. Weight of BIM Challenges in Morocco

Fig. 6 syntheses the collected responses to Likert-scaled question that scaled the challenges' impact on BIM adoption in Morocco from 1(insignificant) to 5(very blocking).

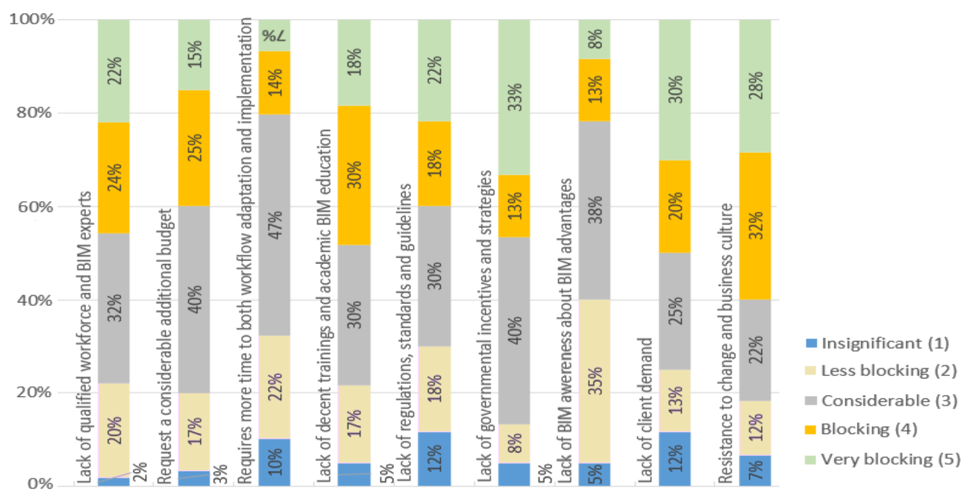

Fig. 4. Weight of BIM challenges in Morocco per scale

The following formula was used to calculate the Average Weight (AW) of each challenge Cht:

$$AW(Ch_t) = \sum_{i=1}^{5} p_i * s_i\,(CH_t) \quad with \begin{cases} t \in \{1,2,3,4,5,6,7,8) \\ s_i = scale\ from\ 1(insignificant)\ to\ 5(very\ blocking) \\ p_i = percentage\ of\ respondents\ giving\ s_i\ to\ the\ CH_t \end{cases} \tag{1}$$

Table I disclosed that challenges due to personal-related and governmental/financial-related factors represent the highest blocking challenges hindering BIM adoption in Morocco, where the AW of "resistance to change and business culture" and "Lack of governmental incentives and strategies" exceeded 3.6. In the same vein, the three more personal-related challenges: "Lack of qualified workforce and BIM experts", "Lack of client demand and buy-in" and "Lack of decent trainings and academic BIM education" are considerable BIM challenges with an AW of 3.4. Meanwhile, the financial challenge "requirement of considerable additional budget" and the governmental challenge "Lack of regulations, standards, and guidelines" seem less impactful but remain considerable. "Requirement of more time to both workflow adaptation and implementation" and "Lack of BIM awareness" are the least impactful challenges in Morocco.

Table 1. Average Weight of listed BIM Challenges

Code	Type	Challenge	AW
Ch8	P	Resistance to change and business culture	3.6333
Ch6	F/G	Lack of governmental incentives and adoption strategies	3.6167
Ch1	P	Lack of qualified workforce and BIM experts	3.4407
Ch7	P/M	Lack of client demand and buy-in	3.4333
Ch4	P/G	Lack of decent trainings and academic BIM education	3.4000
Ch2	F	Requirement of considerable additional budget	3.3167
Ch5	G	Lack of regulations, standards, and guidelines	3.2000
Ch9	P	Lack of awareness about BIM advantages	2.8500
Ch3	M	Requirement of more time to both workflow adaptation and implementation	2.8475

4.4. Additional BIM Challenges in Morocco and validation

The respondents were asked to cite, optionally, other challenges and scale them accordingly (1(insignificant) to 5(very blocking)). As a result, 14 respondents added 21 valid responses converging to two main challenges:

- **Ch10** "Huge use of cracked software licenses": Ch10 was considered as 'very blocking' 7 times and as blocking 3 times. According to the respondents, Ch10 firstly limited project's stockholders to freely exchange their models since the models developed with cracked licenses could carry viruses or malfunction that would harm models done in proper ways. Secondly, afraid of being recognized by the software suppliers and being pursued, the stockholders using cracked licenses refuse to connect their software to the cloud which makes BIM inapplicable.
- **Ch11** "Fierce competition by non-qualified engineering firms / Huge number of unqualified AEC companies proposing tight prices": Ch11 was cited 7 times where 5 scaled it as blocking, 1 as very blocking and 1 as considerable. The respondents explained that, in Morocco, opening an engineering firm is governed by general laws and does not require any level of academic or professional competences to create such companies. Therefore, many people without the required academic or professional skills see in the construction field a profitable business without worrying about the quality of their deliverables. These kinds of engineering firms usually do not call for qualified engineers; instead, they could assign the design tasks to technicians or practitioners in the field! The absence of law in this sense has given rise to many incompetent offices imposing reduced prices and lowering both prices and quality of deliverables in the design market. Considering this situation, BIM adoption would be difficult.

4.5. Validation of newfound BIM Challenges in Morocco:

To confirm the reliability of these two challenges, the authors went through more validation studies.

4.5.1. Ch10: the validation of this challenge was difficult since no related statistics have been found. However, an AEC software and hardware supplier participating in the survey confirmed that since 2013, his company has detected 25 cracked licenses per year on average, especially for Autodesk and Trimble BIM software.

4.5.2. Ch11: For this challenge, two elements were verified: a) the weight of unqualified engineering firms on the Moroccan construction market and b) if the creation of an engineering firm legally needs certain requirements, especially in terms of competencies' level.

- Officially Qualified engineering firms in Morocco:

The Moroccan authorities represented by the Moroccan Ministry of Equipment, Transport, Logistics and Water (METLW) has set in place a FREE certification (The Moroccan METLW, 2021) proving that the accredited firms in a specific discipline have the needed qualifications and adequate materials to accomplish the related missions. Any reliable engineering firm can acquire this certification for free. This certification is mandatory to work in public AEC projects.

Therefore, to verify the weight of unqualified engineering firms in the Moroccan construction market, the authors assessed and compared the number of existing engineering firms and the number of the accredited ones by the METLW (2021).

Table 2. Domain of expertise defined by the METLW

Code	Domain of expertise	AF	Code	Domain of expertise	AF
D3	Urban hydraulics	97	D14	Structural studies	172
D4	Roads, Highways, Transport	142	D15	Lighting and communication networks for general purpose buildings	136
D5	Special structure	101	D16	Fluid networks for general purpose buildings	140
D6	Dams	16	D17	Roads, sanitation networks and drinking water	202
D7	Maritime and river work	38	D18	Low and medium voltage electricity networks, telephone networks and public lighting	68
D8	Defense Engineering works of a specific nature	4	D19	Environmental Impact Studies	79
D9	Agricultural studies	83	D20	Geology, geophysics, hydrology, hydrogeological	38
D10	Industry and energy	30			
D13	General studies	232	D21	Fire safety in buildings	9

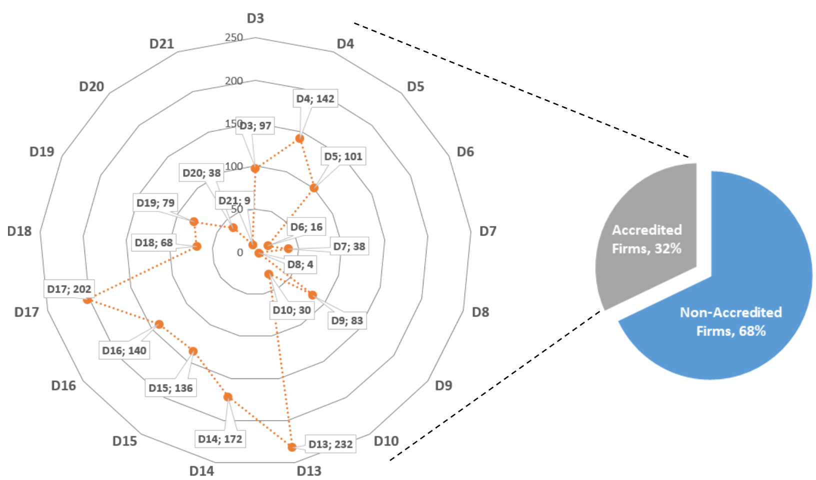

Fig. 5. Repartition of Moroccan engineering firms according to official accreditation by the METLW and Distribution of the accredited ones by domain of expertise.

The census of the accredited firms (AF) by the responsible authority (2021) showed that AF number vary from 4 to 232 according to the domain of expertise (Table 2 and Fig. 7). However, Considering that some engineering firms were simultaneously accredited in 2 or more domains of expertise, a triangulation of the AF in all domains of expertise was processed resulting to a total of 451 AF by METLW. Among them 232 (51%) were accredited in domain 13 “General studies”, 202 (45%) were accredited in domain 17 “Roads, sanitation networks and drinking water” and 172 (38%) were accredited in domain 14 “Structural studies”. Moreover, very few engineering firms were able to present the necessary competences’ proofs in domain 8 “Defense Engineering works of a specific nature”, domain 21 “Fire safety in buildings” and domain 6 “Dams” by presenting.

On the other hand, based on the reputed companies’ database published in Morocco “Charika” (2021), 1412 existing engineering firms active in the 17 domains of expertise were counted. Consequently, less than third (451) of all existing engineering firms in Morocco (1412) were accredited whereas 68% were still not, which confirms the first element of the CH11 (Fig. 7).

- Regulations related to engineering firms’ creation:

To verify this element the authors met the representative of Regional Center of Investment (RCI), Legal authority responsible for procedures of companies’ creation in Morocco, in Casablanca. The representative confirmed that the Moroccan legislation does not require any academic or professional experience for engineering firms’ creation and allows anyone to create and run that kind of companies.

4.6. BIM Perspectives in Morocco

According to the interviewees, BIM was part of the master agreement for the AEC industry development that was signed in 2018 by the 2 professional federations of AEC operators and 8 ministries including the MNTUTPHCP. However, they confirmed that BIM adoption strategy is still in fetus stage. However, considering COVID-19 impacts on the national AEC industry, the government became more interested in developing and implementing a progressive strategy toward BIM adoption. In this vein, the MNTUTPHCP initiated the training of their staff in BIM and created a team, including scholars working in this area, to prepare, by 2022, a first guideline for the ministry to build, plan and implement strategy for gradual mandatory BIM adoption in Morocco.

Likewise, the Moroccan Institute for Standardization developed two projected standards related to BIM and adapted to Moroccan context, they are in validation process:

- PNM ISO 19650-1, IC 10.8.796, 2020: Organization and digitization of information relating to buildings and civil engineering works, including Building Information Modeling (BIM) / Information management by modeling construction information / Part 1: Concepts and Principles,
- PNM ISO 19650-2, IC 10.8.796, 2020: Organization and digitization of information relating to buildings and civil engineering works, including Building Information Modeling (BIM) / Information management by modeling construction information / Part 2: Realization phase of assets.

5. Discussion

The study disclosed that the enforced restrictive measures against the COVID-19 spread helped increase the BIM adoption among Moroccan AEC operators by 19% where 35% of the operators who were not considering BIM adoption rescinded their decision considering its proved abilities to enable remote practices and overcome the challenging work conditions imposed by the COVID-19 in construction projects (Bouhmoud et al., 2022b; Bouhmoud and Loudyi, 2021). Nevertheless, the study confirmed that BIM adoption is still struggling with several challenges headed by personal-related category, which line up with previous studies conducted in other regions (Bouhmoud and Loudyi, 2020; Charef et al., 2019).

“Resistance to change and business culture” is on the top of personal-related challenges’ category, tailed by “Lack of qualified workforce & BIM experts”, “Lack of client demand & buy-in” then “Lack of decent trainings & academic BIM education” that was attributed to the lack of BIM tools, lack of experienced lecturers and the high cost of training for BIM (Shibani et al., 2020). Governmental and financial challenges are the second critical categories of BIM barriers where “Lack of governmental incentives and adoption strategies” is the most impactful. The study revealed that the Moroccan government is still in the ideation phase to prepare a BIM adoption strategy which will keep this challenge on the list of top BIM barriers for some years to come in Morocco. In addition of the worldwide challenges, BIM adoption in Morocco is facing two additional challenges: “Huge use of cracked software licenses”, and “Fierce competition by non-qualified engineering firms / Huge number of unqualified AEC companies proposing tight prices”.

Using cracked software licenses deters the collaboration parameter needed for BIM models as well as their security and reliability. Aleassa et al. (2011) and Bui et al. (2016) reported that this challenge was also detected in several countries headed by 25 developing countries. Moreover, having a large number of unqualified AEC companies, especially related to design stage, is pulling down both prices and quality in the AEC market and thereby disturbing the qualified ones to propose prices allowing using new technologies. This challenge is principally due to a loophole in the Moroccan legislation where neither academic background nor expertise are required for companies’ creation in different AEC expertise areas. For instance, 68% of existing engineering firms in Morocco are not accredited in none of the 17 listed AEC domains of expertise.

6. Conclusion

The AEC industry leads behind the other industries in terms of ICTs use in common practices, mainly in developing countries where this industry is struggling with more financial and technological issues (Kajewski et al., 2001). However, the COVID-19 spread highlighted the urgent need to switch the current used practices in the AEC industry toward more automated and remote ones namely enabled by BIM technology. In the African country Morocco, the pandemic stimulated BIM adoption as it helped the increase of the rate of AEC bodies considering adopting BIM by 19% and the initiation of preparing BIM adoption regulation. However, the undertaken actions by both public and private bodies are still considerably timid considering the significant identified BIM challenges.

BIM adoption in Morocco is still struggling with several challenges where personal-related ones are the weightiest with ‘Resistance to change and business culture” on the top”. Governmental and financial challenges remained also significantly impactful where “Lack of governmental incentives and adoption strategies” headed the list. Moreover, the study highlighted the existence of a considerable loophole in Moroccan legislation that worsen the challenging unfair competition beside the common use of cracked licenses, which may further hamper BIM adoption. Therefore, to lessen these challenges’ impacts and upgrade the national AEC industry toward more efficient and remote practices, the Moroccan policymakers should consider the following measures soon:

- ➔ Create and name a specialized authority responsible for BIM in the local AEC industry,
- ➔ Build founded strategies and timeline for BIM implementation,

- Design adapted BIM standards and guidelines adapted to the local context,
- Create an efficient legal framework including aspects related to contractual environment, ownership parameters, responsibilities…
- Set up considerable incentives both direct and indirect,
- Encourage Research and development,
- Incorporate BIM in academic syllabus, for either engineers, architects, or technicians' programs.

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Drivers for Effective BIM Implementation: PEST and Analytic Hierarchy Process Approach for Sustainable Construction Decision-Making in UAE

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Abstract

Building Information Modeling (BIM) is a cutting-edge technology revolutionizing the construction sector. By strategically adopting and implementing BIM, organizations will significantly improve performance in many aspects, such as programs' efficiency, design quality, waste reduction, and environmental performance of built environment projects. The use of BIM has been widely embraced in the building sector, especially in the UAE, where the presence of foreign enterprises engaged in the building industry has made the monarchy's construction industry one of the most significant marketplaces. The building industry has played a vital role in the UAE's enormous expansion and urbanization of the economy. Thus, BIM is recognized as one of the most significant technological breakthroughs in sustainable construction practice. However, few regulations and policies have been created to implement BIM within the UAE construction industry. The problem is exacerbated by the fact that construction work in the UAE frequently entails high levels of risk, unique technology, and engineering hurdles, such as the ever-changing regulation and environmental risks. Thus, fully implementing BIM presents considerable challenges for the construction industry due to a lack of understanding of the implementation drivers, a lack of BIM assessment tools, and a lack of assessment decision-making tools, which demands constant decision-making-based criteria with continuously renewed project information. Motivated by this need, the study aims to identify and prioritize the main drivers for BIM implementation in the construction industry. To achieve this goal, an integrated PEST and Analytic Hierarchy Process (AHP) analysis were conducted to support the decision maker's understanding of more tangible and practical BIM implementation drivers and examine their ranking and relationships. The study findings showed that the technological aspect was ranked first regarding the main criteria affecting the effective implementation of BIM in the construction industry. In contrast, the socio-cultural aspects were ranked the least compared to the other criteria.

Keywords

BIM, Building Information Modelling, Construction, Sustainability, AHP, PEST, BIM Factors.

1. Introduction

1.1 BIM in the Construction Industry

Building Information Modeling (BIM) has transformed the traditional design and construction process by allowing stakeholders to collaborate on a common digital platform (Azhar et al., 2011). However, there still needs to be a greater understanding of BIM implementation's different aspects and stages, which hinders its full potential (Li & Li, 2013). BIM can transform the construction industry by providing a platform for collaboration and data exchange among various stakeholders. BIM also has the potential to assist in the development of sustainable construction practices using more accurate and efficient energy simulations and life cycle analyses (Rahman et al., 2019). However, the effective implementation of BIM requires meeting specific criteria and has proven to be a challenge in the building sector. Despite the advantages of BIM implementation, several potential issues have been identified recently, such as a lack of standardization in its application to varied building projects, which can result in discrepancies and ineffectiveness in project execution (Bryde et al., 2013; Froese, 2010; Succar, 2009). Venkatachalam. (2017) also notes that the United Arab Emirates is behind other developed countries, such as the United Kingdom and the United States, in terms of implementing BIM; implementation barriers are the primary challenges, such as the lack of BIM proficiency and instruction can hinder teamwork and communication between project participants (Sacks et al., 2018). In addition, Mehran. (2016), discovered that the minimal adoption of BIM in the construction industry in the UAE is the result of a lack of BIM standards and BIM implementation criteria, which leads to resistance to change in the sector. As a result, the United Arab Emirates has not yet caught up with other countries in adopting and implementing BIM for improved performance and efficiency. Various solutions have been proposed to tackle these issues, such as integrating unified country-wide BIM regulations and implementing educational programs for building professionals (Arayici et al., 2011). Overall, BIM adoption can produce a significant enhancement in the construction sector by understanding the main success drivers that take into consideration all the BIM implementation processes (Arayici et al., 2011; Eastman et al., 2011; Bryde et al., 2013; Rahman et al., 2019; Sacks et al., 2018). Many drivers for effective BIM implementation have been identified in the literature. However, till the knowledge of the authors, no studies in the UAE construction industry have grouped and prioritized them according to PEST analysis. As a result, this study aims to identify and prioritize the drivers and factors of BIM implementation as a sustainable construction practice in the UAE, utilizing the Analytical Hierarchy Process (AHP) to prioritize through subject matter experts. In the context of BIM and decision-making, PEST analysis can identify potential risks and opportunities associated with implementing BIM.

1.2 BIM implementation Drivers

BIM implementation factors refer to the characteristics or drivers essential for successfully adopting and using BIM in a construction project or organization. Some of the key BIM implementation attributes include political, economic, socio-cultural, and technological. For example, political factors such as government regulations and policies can affect the usage of BIM in construction plans (Ma et al., 2020; Feng et al.,2020; Dakhil, 2017). Economic factors such as funding and project costs can also impact the implementation of BIM, as mentioned by Du et al. (2018), Kim et al. (2019), and Sabri et al. (2018). Another important driver is the socio-cultural factors, such as the public's perception of BIM and its benefits, which can also play a role in its adoption (Shafiq, M. T, 2021; Li et al., 2020; Bashir & Sika, 2018). Technological factors, such as the availability of BIM software and the level of expertise of users, can also affect the implementation of BIM (Omar et al., 2020). The next part of the literature focuses on identifying the main drivers and factors impacting the BIM assessment and implantation and their contribution to the success of the BIM implementation process grouped as per PEST analysis.

1.3 Political Criteria

A previous study by Dakhil (2017) and Wang et al. (2020) concluded that government policies and regulations play an essential role in facilitating BIM within organizations that adopt policies or regulations that support or mandate the use of BIM, such as building codes or procurement rules. Moreover, previous studies have noted that industry associations may promote the use of BIM through guidelines, standards, or training programs. This has been noted by Ma et al. (2020), Feng et al. (2020), and Keller, K. L. (2016). Dakhil (2017) and Wang et al. (2020)., Another factor influencing BIM implementations is government funding. According to Wang et al. (2020) and Siebelink et al. (2017), governments may provide funding for BIM research and development or for organizations to adopt and implement BIM.

1.4 Economic Criteria

A study by sabri et al. 2018 mentioned that a country's inflation rate might influence the rate of adopting and implementing BIM. This measures the rate at which prices for goods and services are increasing. High inflation can lead to decreased consumer purchasing power and increased business uncertainty. Competitive advantage is another factor tackled in many studies (Chen et al., 2020) and (Alwisy et al., 2019). Adopting BIM may give organizations a

competitive advantage by improving efficiency and quality. This has been noted by Arslan et al. (2020) and Kim et al. (2020) from the Viewpoint of a Construction Project.
Lastly, the cost of implementing BIM and the financial considerations may influence an organization's decision to adopt BIM. This includes the initial investment in software, training, and other resources and the ongoing costs of maintaining and updating the BIM system. Previous studies, such as Du et al. (2018) and Kim et al. (2019), have found that the potential cost savings and efficiency improvements associated with BIM may outweigh the initial investment.

1.5 Socio-cultural criteria:

Adopting BIM may require changes to an organization's culture and values, such as a shift towards collaboration and innovation. This has been noted in a case study from the UAE by (Omar et al., 2020). Another factor is cultural influences; a study of how culture shapes consumer behaviours and decision by Tan et al. (2021) showed that culture could affect the acceptance of new products or services in different regions or countries (Li, Gao, & Lu, 2016). This includes factors such as the population's values, beliefs, and attitudes toward specific industries or technologies (Dalui et al., 2021). Furthermore, previous studies highlighted labour market conditions as one of the main socio-cultural attributes. This includes factors such as unemployment rates and job availability in the construction industry (Kotler, P., 2017; Ma et al., 2018; Lee & Rooke, 2016).
Additionally, skills and training consider one of the factors impacting adopting BIM. Which may require organizations to invest in employee training and development (Wang et al., 2018). According to a study by Ting Wang et al. (2018), the lack of sufficient skills and training is a barrier to adopting and using BIM. The authors found that organizations with more trained BIM personnel were likelier to use BIM effectively. Similarly, a study by Xiaozhi Ma et al. (2018) found that the availability of skilled personnel was a key driver of BIM adoption.

1.6 Technological criteria

The availability of BIM software, hardware, and other technologies may impact an organization's ability to adopt and use BIM (Wang & Feng, 2015). According to a study by Wang and Feng (2015), the availability of BIM technology is a critical factor in adopting and using BIM. The authors found that organizations with access to advanced BIM technology were likelier to use BIM in their projects. Similarly, a study by Xiaozhi Ma et al. (2018) found that the availability of BIM technology was a key driver of BIM adoption. Organizations need the technical infrastructure, software, and training to use BIM effectively. This has been noted by (Xu et al., 2019) and (Babatunde et al., 2018). According to a study by Sabri et al. (2020), the availability of infrastructure and support is a critical factor in adopting and using BIM. The authors found that organizations with robust IT infrastructure and support were more likely to use BIM effectively. Interoperability is one of the main factors addressed by many scholars as one of the BIM implementation drivers. The ability of different software and systems to work together seamlessly is essential to use BIM (Al Hattab et al., 2018). According to a study by Fernanda Leite (2016), interoperability is critical in successfully implementing BIM. The author found that organizations with reliable interoperability between different software systems were more likely to achieve high levels of BIM adoption. Another study by Sander Siebelink et al. (2017) found that interoperability was critical in effectively using BIM in the Dutch construction industry.
Moreover, data management skills are considered another crucial technological factor for BIM implementation. BIM's effective implementation requires the management of large amounts of data, which can be challenging for organizations without robust data management systems. This has been noted by (Guan et al., 2018; Du et al., 2019; Ju & Lu, 2018). To measure the level of BIM implementation within an organization, a variety of dimensions and attributes can be considered, as outlined in Table 1.

Table 1: *Drivers of BIM Effective Implementation.*

No.	***Main Criteria-PEST***	***Sub-criteria Indicator***	
		Name	***References***
1	***Political***	Government Policies and Regulations	Ma et al., 2020; Feng et al., 2020; Keller, K. L., 2016. Dakhil. 2017; and Wang et al., 2020.
		Government Funds	Feng et al., 2019; Zhang et al., 2017;.Wang and Feng (2021),

		Industry Associations	Wang et al., 2019; Wang et al., 2020 and Siebelink et al., 2017; Dalirazar & Sabzi. (2020); Zhang et al., 2017
2	***Economic***	Inflation Rate	Sabri et al., 2018 and Eilifsen et al. (2020)
		Competitive Advantage	Chen et al., 2020; Alwisy et al., 2019; Arslan et al., 2020 and Kim et al. (2020).
		Financial Considerations	Du et al. (2018); Kim et al. (2019); (Wang et al., 2020; Akbarnezhad et al., 2014).
3	***Socio-cultural***	Culture and Values	Kotler, P., 2017; Kazi et al., 2020; Omar et al., 2020.
		Labour Market Conditions	Kotler, P., 2017; Ma et al., 2018; Al Hattab et al., 2018; Sarhan et al. (2019).
		Skills and Training	Ting et al., 2018 ; Xiaozhi Ma et al., 2018; Maskil-Leitan & Reychav, 2018.
4	***Technological***	Availability of Technology	Wang & Feng, 2015; Ma et al., 2018; (Tally, R.S., 2016); Xu et al., 2019; Babatunde et al., 2018
		Interoperability	Wang & Leite, 2016; Siebelink et al., 2017; Hwang & Kim, 2017; (Tally, R.S., 2016)
		Data management skills	Omar et al., 2020.; Sabri et al., 2020; Lucky et al., 2019; Du et al., 2019.

2 Methodology

2.1 Study Area and Data Collection

The study was undertaken in the United Arab Emirates (UAE) and targeted the governmental and private construction sectors. In order to find the drivers for BIM implementation in the UAE, an AHP pairwise comparison questionnaire was constructed. Based on the literature review, 12 factors were selected as sub-criteria according to the most cited literature and then categorized as per PEST analysis, which will be elaborated on in the coming section. The data collection phase was done in two phases, primary and secondary. The primary phase was gathered from a literature review with all driver factors. The second phase was obtained through the questionnaire distributed to the field's subject experts.

2.2 Data Collection and Criteria Selection

At the data collection stage, the data was collected from the population of the United Arab Emirates construction industry. A sample of 48 respondents answered the distributed survey. The selection of BIM implementation drivers required the availability of relevant data; online experts panels interview was used to conduct the multicriteria analysis to rank the drivers based on their importance for the construction industry. To find out the parameters according to expert opinion in prioritizing the BIM implantation driver, an Analytic Hierarchy Process (AHP) pairwise comparison style questionnaire was prepared. Based on the conducted literature review, the following four main criteria and 12 sub-criteria were obtained and applied to the questionnaire construction.

2.3 PEST – AHP Analysis

A PEST analysis is used to study the critical external factors that influence an organization and can guide professionals and senior managers in strategic decision-making. In the context of BIM implementation, a PEST analysis can help identify the political, economic, socio-cultural, and technological factors that may impact the adoption and use of BIM within an organization. AHP is a multicriteria decision-making method developed by Saaty's 1977. Using linear weighing methods of qualitative and quantitative criteria, AHP has been successfully used in many sectors such as government, business, healthcare, and education. Moreover, AHP decision-making includes preferences and experiences. It is the best hierarchical framework for determining each criterion's relative importance. It represents and describes a problem, links its components to the overall objective, and explores alternative solutions to design a decision. AHP helps decision-makers choose the best solution to meet their goal and understand the problem (Abdelkarim et al., 2020; Kuber et al., 2017).

2.3.1 Data Validation and AHP Hierarchical Structure

Once the pairwise comparison matrices had been constructed, the weight of each decision was calculated using standard AHP computation. Then, a consistency ratio was obtained for the consistency of the results (Ng, 2016).
The study built an AHP hierarchy according to the relationship between the main criteria, sub-criteria, and alternatives—the proposed hierarchical structure as illustrated in Figure 1.

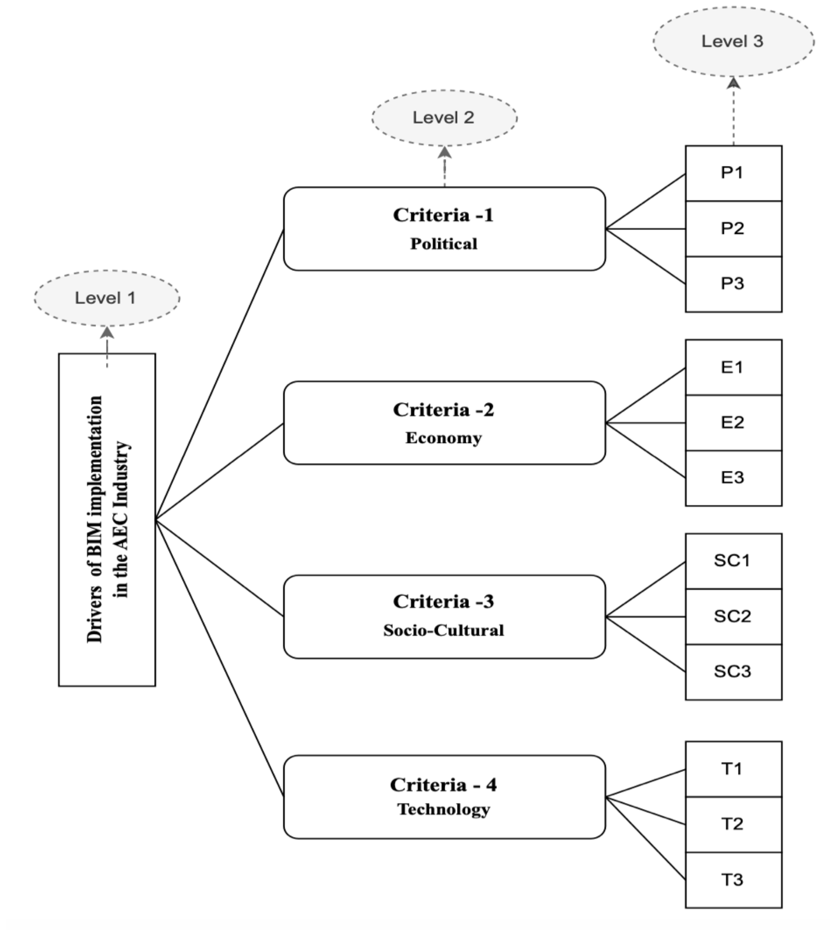

Figure 1:AHP Hierarchy Structure

3 Results

3.1 Demographics Results

After identifying the factors of BIM implementation from the literature review, as shown in Table.1. Some factors were selected which were relevant to the case in this study and categorized based on PEST categorization, as defined in the methodology section and Table.1. The gender distribution was almost 60% males and 40% females. The reason for that percentage is that most of the experts who work in the construction industry are male. The questionnaire targeted subject of experts from different job position levels (15.7% entry level, 35.31% analyst, 44.6% managerial level, and 5.2 % c-suite level) such as project managers, BIM managers, and contracting companies' managers in both private and governmental sector the former with 57% and the latter with 43% of the responses.

3.2 AHP Results

The pairwise comparison matrix was conducted for the main criteria, namely political, economic, socio-cultural, and technology, for all the 48 responses results based on Saaty's scale. Furthermore, all the comparison matrix was aggregated using the geometric mean method in one final comparison matrix (aggregated), and the local weights were calculated from the comparison matrix. The exact process has been followed for all sub-criteria to make the pairwise comparison matrix Table 2 shows the comparison matrix of the main criteria and their respective weights.

Table 2: Pairwise Comparison Matrix of Main Criteria (Aggregated)

Main Criteria	*Political*	*Economic*	*Technology*	*Socio-cultural*	*Criteria Weights*
Political	1	1.461004	0.835084	0.694968	0.242014
Economic	0.684461	1	0.872483	1.697385	0.252193
Technology	1.197485	1.146153	1	1.317931	**0.279641**
Socio-cultural	1.438914	0.589142	0.758765	1	**0.226152**

The exact process for all sub-criteria to do the pairwise comparison matrix has been followed. Tables 3, 4,5, and 6 show the pairwise comparison matrix of political, economic, socio-cultural, and technology, respectively, assigned with their weights.

Table 3: Pairwise Comparison Matrix of Sub-criteria - Political (Aggregated)

Political	*Government Policies and Regulations*	*Government Policies and Regulations*	*Government Policies and Regulations*	*Criteria Weights*
Government Policies and Regulations	1	1.304779	1.054818	0.369584
Government Funding	0.766413	1	1.075166	0.311661
Industry Associations	0.948031	0.930089	1	0.318755

Table 4: Pairwise Comparison Matrix of Sub-criteria – Economic (Aggregated)

Economic	*Inflation Rate*	*Competitive Advantage*	*Financial Considerations*	*Criteria Weights*
Inflation Rate	1	1.70979	2.413424	0.2728
Competitive Advantage	0.584867	1	1.649636	0.3068
Financial Considerations	0.414349	0.606194	1	0.1959

Table 5: Pairwise Comparison Matrix of Sub-criteria – Socio-cultural (Aggregated)

Socio-cultural	*Culture and Values*	*Labour Market Conditions*	*Skills and Training*	*Criteria Weights*
Culture and Values	1	1.077429	1.542646	0.1959
Labour Market Conditions	0.928136	1	1.21038	0.3901
Skills and Training	0.648237	0.826187	1	0.3423

Table 6: Pairwise Comparison Matrix of Sub-criteria – Technology (Aggregated)

Technology	*Availability of Technology*	*Interoperability*	*Data management skills*	*Criteria Weights*
Availability of Technology	1	1.02972	0.55739	0.4975
Interoperability	0.971138	1	0.858323	0.3087
Data management skills	1.794076	1.165063	1	0.4184

The consistency ratio for all criteria is listed in Table 7. All the consistency ratios are less than 0.1. So, all the criteria consistently create the overall weightage for BIM drivers' analysis. After comparing the consistency ratio analysis, the weights of the main criteria and their respective sub-criteria are multiplied to create overall global weights. The overall global weights are multiplied by 100 to calculate the percentage of every sub-criterion. Table 8 presents the percentage of every sub-criteria weights.

Table7: Consistency Ratio for All Criteria

Main and Sub-criteria	Consistency factors	Consistency Ratio
Main criteria	*Political* *Economic* *Socio-cultural* *Technological*	**0.005134**
Political	*Government Policies and Regulations* *Government Funding* *Industry Associations*	**0.008869**
Economic	*Inflation Rate* *Competitive Advantage* *Financial Considerations*	**0.003228**
Socio-cultural	*Culture and Values* *Labour Market Conditions* *Skills and Training*	**0.021302**
Technological	*Availability of Technology* *Interoperability* *Data management skills*	**0.0026938**

Table 8: Weights Derived from Performing Analytical Hierarchical Process

Main Criteria	*Weights of Main Criteria*	*Sub Criteria*	*Weights of sub criteria*	*Global weights (%)*	*Global Rank*
Political	0.2420	*Government Policies and Regulations*	**0.3696**	**8.94 %**	**3**
		Government Funding	0.3117	7.54 %	10
		Industry Associations	0.3187	7.71 %	8

Economic	0.2522	*Financial Consideration*	0.2728	7.63 %	9
		Competitive Advantage	0.3068	7.73 %	7
		Inflation Rate	**0.1959**	**4.94 %**	**12**
Socio-cultural	**0.2264**	***Culture and Values***	**0.3901**	**8.82 %**	**4**
		Labour Market Conditions	0.3423	7.77 %	6
		Skills and Training	0.2675	6.05 %	11
Technological	**0.2796**	***Availability of Technology***	**0.4975**	**12.55 %**	**1**
		Interoperability	0.3087	8.63 %	5
		Data management skills	0.4184	11.70 %	2

4. Discussion

The technological aspect was ranked first in terms of the main criteria. Overall, the technological aspects of the availability of technology and data management skills were ranked higher globally, contributing to the highest rank of the technological driver. This means that the technological capabilities of an organization are considered a key factor when implementing BIM, which complies with Wang & Feng (2015) and Ma et al. (2018). The last ranked factor in this aspect was Interoperability. Although the BIM implementation required a complex interaction between different data types and activities, understanding this concept would take much work in certain areas. It would not be capable of operating with that challenge.

The second-ranked main driver was economics. In this crucial aspect, it was provided by the expert panel that the competitive advantage was the highest ranked, as this means that the implementation can only achieve with an understanding of the competitive advantages of implementing BIM effectively. In addition, the financial consideration that would support the adoption was ranked second due to the importance of the financial support to facilitate the process of implementation in terms of resources and the financial capacity to withstand the demanding of this technology within the industry, which conform with the same findings of Du et al. (2018) and Kim et al. (2019), as they support this by indicating the importance of a well-planned financial plan and cash flow to support the BIM implementation in the construction industry. The inflation rate was ranked the least in terms of importance as understanding the indirect financial dimensions. The inflation rate might affect the BIM implementation at the regional level rather than the organizational level, which complies with Sabri et al. (2018) and Eilifsen et al. (2020).

However, the result indicated that the political driver was ranked third in importance for BIM implementation. The Government Policies and Regulations factors were ranked third globally. Wang et al. (2020) and Siebelink et al. (2017) note that governments may fund BIM research and development for organizations to adopt and facilitate BIM implementation in the construction industry.

Moreover, the socio-cultural aspect was ranked the least in terms of the main criteria. Because it does not provide a significant impact, technology can be rented to do particular work within the industry. However, from this aspect, the value and cultural norms were ranked fourth in the global ranking as the cultural norms and values of the different industry parties affect the BIM implementation. BIM adoption may also require changes to an organization's inherent culture and values, such as a shift toward collaboration and innovation. This factor was noted in a previous study by Shafiq, M. T. (2021) about client-Driven Level-2 BIM implementation.

5. Conclusions and Recommendations

The literature indicated that BIM is essential to enhance construction project performance throughout the project lifecycle. Moreover, it demonstrated that effective implementation and assessment of the BIM process increase the project's productivity, profitability, and business opportunities created by assessing and enhancing the management process, consequently enhancing the project performance. The BIM technique is used to retain and create information

on a project's construction during each phase of its life cycle. This process comprises the formation of a coordinated visual depiction of each element of the produced thing utilizing suitable technology. Therefore, AHP analysis was done to assess the drivers gathered from the literature review hindering BIM implementation in the construction industry. The drivers were categorized into four main criteria based on PEST analysis: political, economic, socio-cultural, and technology, and under each criterion, three sub-criteria.
Moreover, the study sought to quantify and rank the relevant BIM drivers to assist decision-makers in deciding on their BIM implementation level. The results showed that the main driver influencing the BIM implementation was technology which ranked first among them. In summary, the construction sector can benefit from this study to develop a more reliable framework and assessment tool to measure the level of BIM implementation using the extracted factors and to overcome the challenges related to practical implementation to satisfy the targeted stakeholders.

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Awareness Level of Construction Professionals Towards Futuristic Building Materials in South Africa

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Abstract

The global quest and concerted efforts towards achieving sustainability in the construction industry (CI) are hampered by many factors. An example of such a factor is the continued patronage specification and use of conventional construction materials with severe environmental impacts. To overcome this challenge, the availability, awareness, adoption, and utilisation of building materials and technologies with sustainable attributes are imperative. A class of materials in this category are the futuristic building materials (FBMs) known to possess eco-friendly attributes and are highly effective in realising the sustainability agenda of the CI. Hence, this study examines the awareness level of FBMs among construction professionals in South Africa. This study employed the quantitative research method. A well-structured questionnaire survey was administered to duly registered and practicing construction professionals in the South African construction industry (SACI). The duo of descriptive and exploratory factor analysis was used to analyse the collected data. Findings from the study showed fifteen (15) FBMs in their order of awareness. Wood, recycled plastic, bamboo, rammed earth, and timbercrete are identified as the top FBMs known to construction professionals in the SACI. Conclusively, the result further reiterated the general knowledge that construction professionals are reluctant to change thereby limiting their awareness level and use of the FBMs. It is therefore recommended that a multi-stakeholder approach is directed toward FBMs to ensure their proliferation, adoption, and use in the CI.

Keywords

Built Environment, Construction Materials, Futuristic Building Materials, South Africa, Sustainable Construction.

1. Introduction

There are numerous socioeconomic benefits traceable to the construction industry (CI). To mention a few, these benefits are employment/job creation, and provision of basic and critical infrastructures such as roads, power plants, hospitals, schools, rails, and many more. In the process of providing these amenities, the global CI now contributes significant negative environmental impacts, primarily due to the excessive use of natural resources and massive generation of waste. By nature, construction activities are not environmentally friendly (Lu & Tam, 2013). The extraction and transportation of construction raw materials such as timber, gravel, and sand contribute to deforestation, soil erosion, and pollution (air and water) among others (Ayarkwa et al., 2014). Furthermore, the production of construction materials such as cement and steel is known to be energy intensive (Hammond & Jones, 2008), and results in the emission of greenhouse gases (GHGs), which largely contribute to climate change. The conventional construction processes still majorly undertaken by most construction professionals also consume large amounts of energy, leading to further emissions of carbon dioxide and other pollutants into the atmosphere.

Other significant adverse environmental impacts of the CI are waste generation, loss of biodiversity, and natural ecosystems. Construction sites generate vast amounts of construction and demolition (C&D) waste, including building materials, packaging, and demolition debris (Mah et al., 2018). These wastes take up valuable landfill space, contribute to air, land, and water pollution, and cause the deterioration of the environment. Additionally, the indiscriminate disposal of hazardous materials such as lead paint and asbestos has the potential to pose a threat to human health and the environment. The CI needs to implement better waste management practices to reduce its environmental impact. The CI also impacts the environment through the loss of natural habitats and biodiversity. Buildings and infrastructural developments often require the clearing of forests and other natural areas, leading to the displacement of wildlife and loss of biodiversity. The destruction of natural ecosystems can have long-term consequences for the environment and society, including the loss of natural resources, reduced soil quality, and decreased water availability. To minimize the negative impact on the human and natural environment, the CI must consider the environmental impact of construction activities, minimise the use of traditional building materials with unsustainable attributes and implement measures to mitigate these impacts (Oguntona & Aigbavboa, 2019). Hence, the concept of sustainability creates a consciousness around the social, economic, and environmental footprints of human activities.

According to the WCED, SD is a global concept that aims to meet the needs of the present without compromising the ability of future generations to meet their own needs (Imran et al., 2014). It is a holistic approach to development that encompasses and considers the social, economic, and environmental dimensions. The goal of SD is to strike a balance between economic growth, social equity, and environmental protection. To achieve this goal, a long-term perspective, and a commitment to finding solutions that benefit both people and the planet is imperative. A key principle of SD is the idea of intergenerational equity. This means that the onus is on the people to ensure that the resources and opportunities available today are not depleted or destroyed in a way that will prevent future generations from being able to partake of the same benefits. This requires a focus on long-term planning and decision-making, and a willingness to make sacrifices today to ensure a better future for posterity. The concept of SD also requires a commitment to social equity which is highly pronounced in the 2030 Sustainable Development Goals (SDGs) of the United Nations. This means that work must be done to ensure that everyone has access to the resources and opportunities required to live a fulfilling life, regardless of factors such as income, gender, and race among others. This includes access to education, healthcare, clean water and sanitation, and basic human rights. By promoting social equity, a more stable and prosperous society will be created to benefit everyone, not just a privileged few. The significance of SD, therefore, was what culminated in the notion of sustainable practices in the CI.

Sustainable construction (SC) is an approach or concept in the CI to reduce the environmental impacts of construction activities while creating buildings and infrastructure that are durable, safe, and functional. This concept involves the utilisation of eco-friendly materials, the design and development of energy-efficient buildings, and minimising waste throughout the construction process. The concept of SC also considers the long-term environmental impact of buildings and infrastructure, ensuring that they are built to last and can be easily maintained. Energy efficiency is another critical component of SC. This involves designing, constructing, operating, and maintaining buildings that are energy-efficient and use renewable energy sources such as solar and wind. Energy-efficient buildings reduce GHG emissions and energy costs, ensuring their sustainability in the long run. Other strategies for energy efficiency include using natural ventilation, insulation, and efficient lighting systems. By adopting SC practices, we can create buildings and infrastructure that are environmentally friendly, cost-effective, and long-lasting.

One of the key principles of SC is the use of environmentally friendly building materials. This includes using materials that have a low carbon footprint, renewable, recyclable, reusable, energy-efficient, and are sourced from sustainable sources (Akadiri et al., 2012). Examples of sustainable materials include recycled steel, bamboo, and reclaimed wood. The concept of SC also involves using materials that have a long lifespan, reducing the need for frequent replacements and reducing waste. A major class of material in this category is futuristic building materials (FBMs). Therefore, maximising the potential and benefits of FBMs and other sustainable materials relies solely on their awareness, acceptance, adoption, specification, patronage, and implementation by relevant stakeholders in the CI. Hence, this study seeks to assess the awareness level of FBMs among construction professionals in the South African construction industry (SACI).

2. An Overview of Futuristic Building Materials

As technology continues to advance and the global clamour for sustainability, novel, and sustainable materials will continue to emerge, providing more breakthroughs for the construction industry (CI). Futuristic building materials (FBMs) offer the prospect of designing and building structures that are durable, strong, energy-efficient, and environmentally friendly due to their characteristics (Khitab et al., 2015). These materials are a crucial component of the sustainable construction concept. Examples of FBMs include graphene, aerogel, spider silk, mycelium, biochar, ferrock, straw bale, papercrete bricks, ashcrete, self-healing concrete, timbercrete, rammed earth, bamboo, recycled plastic, bio-plastics, wood, transparent wood, carbon fiber reinforced polymers, and 3D-printed concrete among others. These materials are durable, sustainable, cost-efficient, energy-efficient, superior insulation, strong and resistant to damage, lightweight, flexible, resistant to natural disasters, aesthetically superior, improve health and safety, improve acoustics, reduce waste, reduce carbon footprint, improve air quality, improve weather resistance, and increase building lifespan (Khamidi et al., 2014; Kariyawasam & Jayasinghe, 2016; Ribeiro et al., 2016; De Luca et al., 2023; Panda et al., 2017; De Belie et al., 2018; Ghosh, 2018; Layla et al., 2019; Olofinnade et al., 2021).

Despite the numerous benefits associated with FBMs, there are a few hindrances associated with their adoption and use within the CI. These issues are related to limited availability, cost, lack of awareness, resistance to change among professionals, complexity, regulatory issues, compatibility issues, technical challenges, cultural barriers, limited versatility, security concerns, low patronage, low client demand, and supply chain disruptions among others. Therefore, robust and widespread awareness and education on the benefits of FBMs are imperative to drive their adoption in the CI. Also, a multistakeholder partnership with research entities, industry experts, government, professional bodies, international agencies, and higher education institutions is another path to the proliferation and utilization of FBMs in the CI. Hence, the significance of this study is to assess the awareness level of construction professionals on FBMs in the SACI.

3. Research Methodology

The quantitative method of research was utilised in this study to assess the awareness level of FBMs among construction professionals in the SACI. To achieve this objective, a well-structured close-ended questionnaire survey was prepared and administered to the respondents. The respondents are practicing and duly registered construction professionals within the Gauteng province of South Africa which is the research study area. The respondents sampled are construction project managers, mechanical engineers, construction managers, quantity surveyors, civil engineers, architects, town planners, and project managers who are actively affiliated with their respective professional bodies. The questionnaire provided the respondents with fifteen (15) FBMs that are identified through a review of extant literature. The questionnaire was prepared using a five-point Likert awareness scale. To ensure their completeness and usefulness for the analysis, the completed questionnaires were reviewed and cleaned. The study employed both descriptive and exploratory factor analysis (EFA) methods to analyse the retrieved and collated data. The study achieved a Cronbach alpha value of 0.924 thereby giving credence to the reliability of the data collection instrument and the correctness of the collated results.

4. Findings and Discussions

The analysis of the background information of the respondents showed that 64% of the population sample are males while females represent 36%. Also, 23.4% of the respondents are construction project managers, 21.6% are construction managers, 19.8% are quantity surveyors, 14.4% are civil engineers, 12.6% are project managers, 3.6% are architects, 2.7% are town planners, and mechanical engineers account for 1.8%. A total of 40.5% of the respondents work for consulting firms, 31.5% work for the government, and 28% work for contracting entities. Respondents with five and below years of experience in the CI account for 38.7%, 5-10 years of experience account for 20.7%, 10-15 years of experience account for 12.6%, 15-20 years of experience account for 10.8%, and respondents with more than 20 years of experience account for 17.2%.

4.1 Descriptive Analysis: Awareness Level of Futuristic Building Materials

A total of fifteen (15) FBMs were identified and extracted for use in this study after a concise review of relevant scholarly research publications. Based on the data retrieved and collated, a mean item score (MIS) analysis was performed on the identified variables. Table 1 below presents the results of the analysis. The table presents data on the awareness level of futuristic building materials in South Africa. The materials are ranked based on their mean score, with wood being the most familiar and aerogel being the least familiar among the respondents. Wood had the highest mean score of 4.59, indicating that it was the most well-known futuristic building material. Recycled plastic was ranked second with a mean score of 4.05, followed by bamboo with a mean score of 3.41. Rammed earth and timbercrete were ranked fourth and fifth, respectively, with mean scores of 3.13 and 3.11. The least familiar materials among the respondents were aerogel, spider silk, graphene, and mycelium, with mean scores of 1.97, 2.06, 2.10, and 2.12, respectively. The overall standard deviation ranged from 0.813 for wood to 1.517 for self-healing concrete, indicating varying levels of familiarity among the respondents for each material.

Table 1. Awareness level of futuristic building materials in South Africa.

Materials	Mean Score	Standard Deviation	Ranks
Wood	4.59	0.813	1
Recycled Plastic	4.05	1.099	2
Bamboo	3.41	1.372	3
Rammed Earth	3.13	1.490	4
Timbercrete	3.11	1.377	5
Self-healing concrete	3.01	1.517	6
Ashcrete	2.97	1.436	7
Papercrete bricks	2.95	1.285	8
Straw bale	2.84	1.468	9
Ferrock	2.22	1.384	10
Biochar	2.20	1.197	11
Mycelium	2.12	1.270	12
Graphene	2.10	1.243	13
Spider Silk	2.06	1.267	14
Aerogel	1.97	1.171	15

4.2 Exploratory Factor Analysis: Awareness Level of Futuristic Building Materials

Further to the descriptive analysis carried out on the retrieved data, exploratory factor analysis was done. Table 2 shows the results of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity. The KMO value of 0.877 indicates that the sample size is adequate for factor analysis. Bartlett's Test of Sphericity has a chi-square value of 1002.213 with 105 degrees of freedom and a p-value of 0.000, indicating that the correlation matrix is significantly different from an identity matrix, and factor analysis can be used to extract meaningful factors from the data.

Table 2. KMO and Bartlett's Test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.877
Bartlett's Test of Sphericity	Approx. Chi-Square	1002.213
	df	105
	Sig.	0.000

Table 3 shows the communalities of futuristic building materials (FBMs) in South Africa using the principal component analysis (PCA) extraction method. Communalities represent the proportion of variance in each variable that can be explained by the factors extracted. The initial communalities of all variables are 1.000 because they are extracted from the same set of data. The extraction communalities range from 0.572 (Rammed Earth) to 0.793 (Graphene), indicating that the factors extracted account for a considerable amount of variance in the variables. The results suggest that the variables are suitable for further analysis using PCA.

Table 3. Communalities of FBMs in South Africa.

	Initial	Extraction
Aerogel	1.000	0.602
Graphene	1.000	0.793
Mycelium	1.000	0.776
Bamboo	1.000	0.601

Timbercrete	1.000	0.676
Papercrete bricks	1.000	0.586
Biochar	1.000	0.650
Recycled Plastic	1.000	0.681
Wood	1.000	0.678
Spider Silk	1.000	0.635
Ferrock	1.000	0.748
Straw bale	1.000	0.593
Self-healing concrete	1.000	0.605
Rammed Earth	1.000	0.572
Ashcrete	1.000	0.651
Extraction Method: Principal Component Analysis.		

The variance of the components was extracted, and it was discovered that the first component has the highest initial and extraction sums of squared loadings, explaining 48.697% of the variance with eigen value of 7.305 in the data. The second and third components also have relatively high extraction sums of squared loadings, explaining 10.033% and 6.915% of the variance together with 1.505 and 1.037 eigen values, respectively. The remaining components explained less than 6% of the variance each. Hence, the three components were extracted as evident from the Scree plot shown in Figure 1.

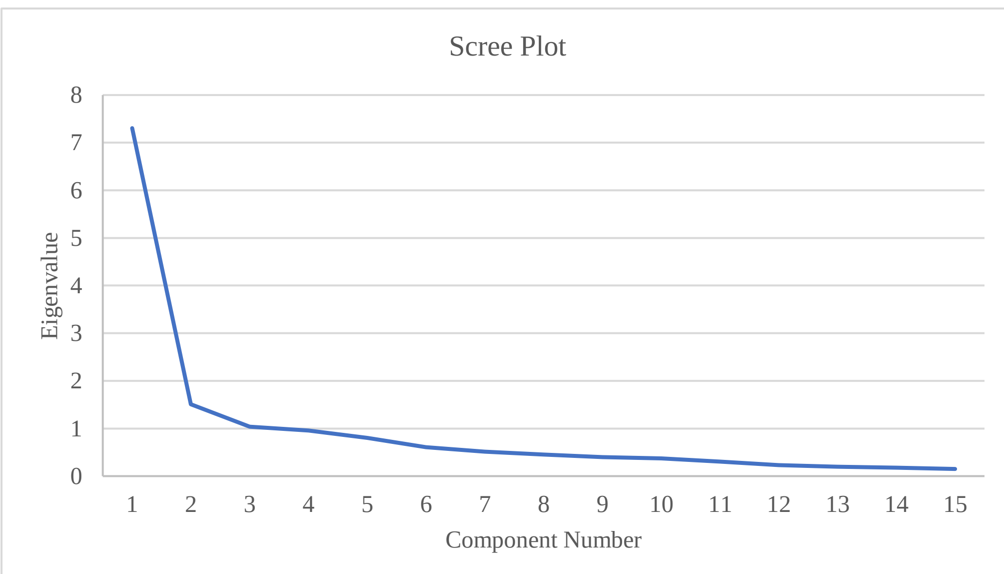

Fig. 1. Scree plot for FBMs in South Africa.

Table 4 presents the pattern matrix for FBM in South Africa after performing principal component analysis with oblique rotation. The matrix shows the correlations between each of the FBM and the extracted components. The table shows three components with corresponding loadings for each of the FBM. Only the loadings with an absolute value greater than 0.5 are considered significant. The FBM with significant loadings on a particular component is said to be associated with that component.

From the table, the first component is associated with mycelium, graphene, biochar, aerogel, self-healing concrete, recycled plastic, and wood. These materials are positively correlated with each other, suggesting that they share common characteristics and may be used interchangeably in building construction. The second component is associated with bamboo, papercrete bricks, timbercrete, and ferrock, and is negatively correlated with the first component. These materials may have unique properties that distinguish them from the materials associated with the first component. The third component is associated with ashcrete, straw bale, spider silk, and rammed earth and is negatively correlated with the first and second components. These materials may also have unique properties that distinguish them from other materials. Overall, the pattern matrix provides information on the relationships between FBMs in South Africa and the extracted components, allowing for a better understanding and classification of these materials based on their characteristics and potential applications.

Table 4. Pattern Matrix for FBMs in South Africa.

	Component		
	1	2	3
Mycelium	0.933		
Graphene	0.910		
Biochar	0.705		
Aerogel	0.642		
Self-healing concrete	0.548		
Wood		0.801	
Recycled Plastic		0.731	
Bamboo		0.544	
Ashcrete			-0.865
Papercrete bricks			-0.761
Timbercrete			-0.718
Ferrock			-0.689
Straw bale			-0.618
Spider Silk			-0.558
Rammed Earth			-0.502

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
a. Rotation converged in 13 iterations.

There are numerous benefits to using different types of FBM in South Africa. Mycelium, for instance, is a versatile and sustainable material with potential applications in many fields such as construction, packaging, and furniture (Yang et al., 2021). Graphene, on the other hand, has high strength and conductivity and can be used to make lightweight, durable, and efficient energy storage devices (Ali et al., 2022). Biochar is a soil enhancer that helps to increase crop yield and reduce greenhouse gas emissions (Vijay et al., 2021).

Also, aerogel is a lightweight and highly insulating material that can be used in building insulation, aerospace applications, and many other fields. Self-healing concrete has the potential to reduce maintenance costs and increase the durability of concrete structures (Berardi, 2019; De Belie et al., 2018). Wood is a renewable and sustainable building material with numerous environmental and aesthetic benefits. Bamboo is a fast-growing and renewable resource that has high strength and versatility, making it an ideal material for a variety of applications. Recycled plastic can be used to create durable and lightweight building materials that help reduce plastic waste in the environment (Robert, 2010; Lamba et al., 2022).

Furthermore, ashcrete, papercrete bricks, and timbercrete are all sustainable and eco-friendly alternatives to traditional concrete that can be used in construction (Pranav et al., 2020). Ferrock is an innovative and sustainable material made from waste steel dust and silica that has the potential to replace traditional concrete. Straw bale construction is an eco-friendly and energy-efficient building technique that uses straw bales as a structural element (Akadiri et al., 2012). Spider silk has high strength and elasticity, and its potential applications range from textiles to medical devices. Finally, Rammed Earth is a sustainable and low-cost building material that is ideal for hot and dry climates (Khitab et al., 2015).

5. Conclusions and Recommendations

In conclusion, the study analysed the awareness level of futuristic building materials (FBM) in South Africa. The sample size included respondents with varied levels of experience and represented different professions within the construction industry. Descriptive and exploratory factor analysis were performed on the data retrieved from the questionnaire, and the results showed that wood, recycled plastic, and bamboo were the most familiar materials among respondents, while aerogel, spider silk, graphene, and mycelium were the least familiar. PCA extraction method on EFA was used to further analyze the data, and the results showed that the FBM were grouped into three components based on their characteristics. Based on the findings, it is recommended that stakeholders in the construction industry in South Africa should consider educating professionals on the potential benefits of using futuristic building materials in construction projects. Additionally, the government could provide incentives to encourage the use of these materials, which could lead to a more sustainable construction industry. It is also recommended that future studies investigate the barriers and drivers to the adoption of futuristic building materials in South Africa to develop appropriate strategies to address them. The study could also be replicated in other countries to compare the results and gain a better understanding of the level of awareness of futuristic building materials globally.

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Development of a Multi-life cycle assessment framework for temporary modular housing

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Abstract
In recent years, temporary modular housing (TMH) has been widely built worldwide to satisfy the housing requirements of vulnerable groups. Although the environmental and economic benefit of TMH relocation is potentially exciting, little is known about the environmental and economic impacts of TMH that are evaluated across its whole life cycle. This study proposes a new framework to assess TMH's environmental and economic impacts over several life cycles, which was created based on the concept of multi-life cycle assessment (MLCA) and multi-life cycle costing (MLCC). Besides, to better understand the comprehensive performances of TMH deconstruction, a single index will be computed to uniform the economic and environmental impacts. The proposed framework consists of three modules: the input module, the assessing module, and the output module. The input module is used to manage the inventory and other pertinent data. The scope and method of assessment are provided by the assessment module. Finally, the evaluation results and a sustainability index will be given in the output module. This research contributed to producing a new evaluation guideline for TMH that explains how modular units can be better built to achieve multi-life cycle environmental and economic sustainability.

Keywords
multi-life cycle assessment, multi-life cycle costing, temporary modular housing, circular economy.

1. Introduction

The building sector, a large contributor to the global economy, greatly affects sustainable development by increasing resource consumption and waste generation. A building significantly impacts the environment, economy, and society throughout its life cycle, from the extraction of raw materials to the end of life. Globally, there is a growing demand for sustainable buildings due to population expansion and resource scarcity. In recent years, temporary modular housing (TMH) has been an appropriate solution to satisfy sustainable demands. This type of building is becoming increasingly popular in many places due to its rapidity and economic feasibility. TMH can be moved and reused several times due to its modular designs, undergoing multiple life cycles. By decreasing the use of virgin resources, minimizing demolition waste, and preserving economic and environmental value, which implements the circular economy (Yang et al., 2022).

Most of the existing sustainability assessment methodologies place a greater emphasis on the single life cycle. Researchers from the TU Delft and other European universities have made the first steps toward developing methodologies for assessing the environmental impact of building components over the multi-life cycle environmental impact and multi-life cycle economic impact in the context of circular construction. For instance, van Stijn et al. (2021, 2022) and Wouterszoon Jansen et al. (2020) assess several kitchen design solutions' environmental and economic impacts over the course of a multi-life cycle. Also, Cascione et al. (2022) evaluated the environmental performance of bio-based wall panels. Although the environmental and economic gains of TMH relocation are potentially exciting little is known about: how the environmental and economic impacts of TMH are assessed from the multi-life cycle point of view. Therefore, this study will further complete the multi-life cycle assessment (MLCA) and multi-life cycle costing (MLCC) methods and propose a new framework to assist assessment and comparison of the multi-life cycle environmental and economic impacts of TMH. The study's results will include recommendations for improving the modular unit design to achieve multi-life cycle environmental and economic sustainability.

This research will distinguish itself from the others by (i) including building services in the multi-life cycle impact analysis, an area that lacks prior research attention; (ii) developing a new approach to improve the evaluation efficiency of the multi-life cycle impact analysis; and (iii) developing an evaluation guideline for TMH to attain its multi-life cycle sustainability.

2. MLCA framework.

This study's proposed framework was derived from the logical evaluation framework for sustainable building. It consists of three modules: an input module, an assessment module, and an output module. The critical elements collected from a comprehensive analysis are incorporated into various modules, as shown in Fig. 1. The input module defines the goal and scope and provides a life cycle inventory for sustainability assessment. The assessment module quantifies the environmental and economic impacts based on the normalized methods. The output module provides the sustainable index and evaluation outcomes.

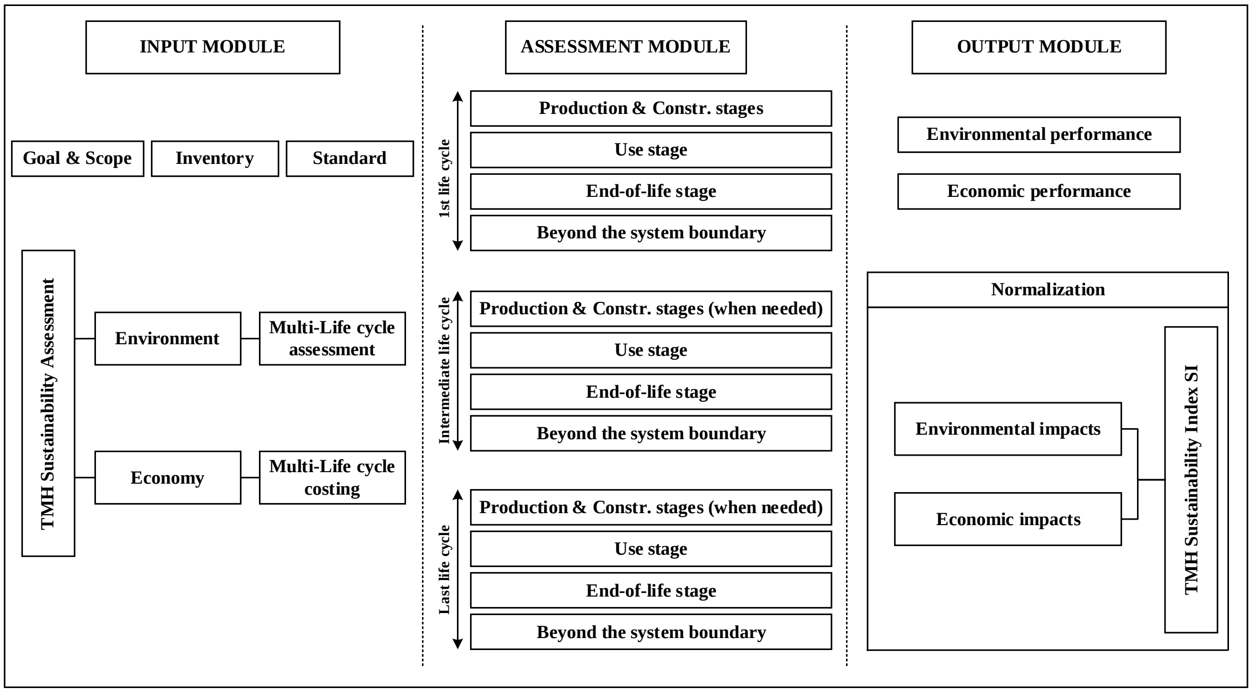

Fig. 1. Framework for TMH sustainability assessment.

2.1 Input module

The input module manages the input information, including data collecting and processing, and provides the goal-inventory-standard hierarchy. The goal is to quantify TMH's environmental and economic impacts throughout its multi-life cycle, from the initial to the end. When developing the framework based on the three pillars concept, only the environmental and economic impacts are considered. There are numerous environmental impact categories that differ between countries and assessment standards. The present study evaluates the environmental performance with the global warming potential (100a), since embodied carbon is typically used as the accounting unit of environmental performance. The life cycle cost is chosen as the economic performance criterion, and among the many costs involved in the life cycle of TMH, initial investment cost, maintenance cost, disassembly cost, and disposal cost are taken into account. The life cycle inventory includes geometric data, unit impact factors, and project documents. Geometric data is typically extracted from 2D drawings and 3D models; impact factors include unit cost and emission factor, which can be obtained from professional databases and standard datasets; and project information is obtained from contractors and suppliers.

2.2 Assessment module

According to Europe Norm 15978 (2011), the life cycle stage of a building (component) - and system boundary of the LCA - is divided into four Modules: A (production and construction), B (usage), C (end-of-life), and D. (benefits and loads beyond the system boundary). Based on the standard framework, the life cycle stages of TMH per cycle are depicted in Figure 2. To avoid duplicate calculations, the sub-processes involved in each life cycle step should be distinguished. In the initial life cycle, for example, Module A includes production, transportation, and installation. Module A in the intermediate lifespan includes the re-assembly of reusable modular components as well as the manufacture of new modular units as needed. Module B is the usage of modular units, which will encompass repair and maintenance while excluding energy and water use for operation (Minunno et al., 2020). The proposed MLCA and MLCC techniques will concentrate on the environmental and economic implications inside and outside the evaluated modular units over numerous life cycles (van Stijn et al., 2021). Modular units, for example, can be repaired and reused within the same system or recycled as secondary materials utilized elsewhere.

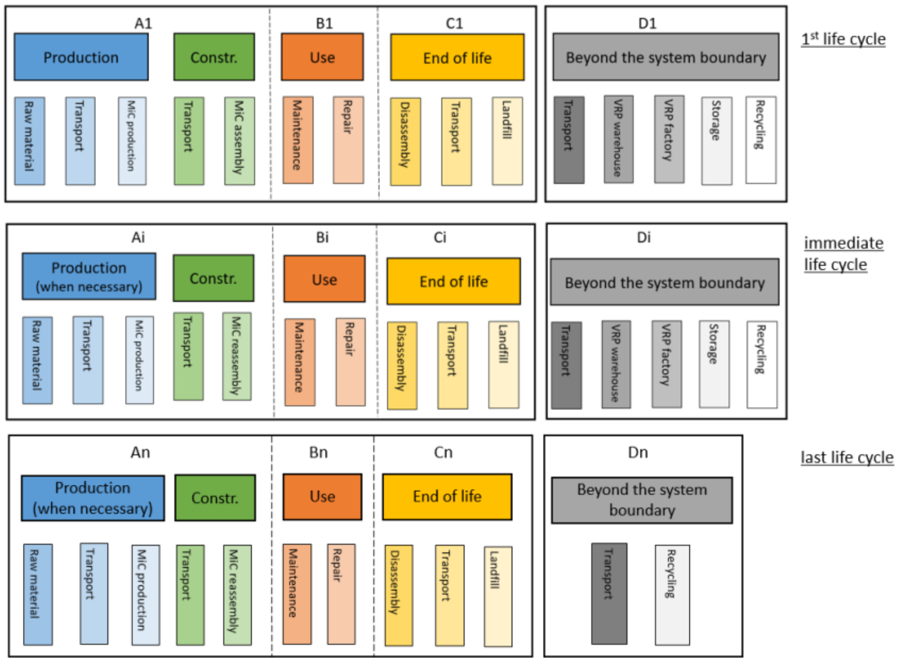

Figure 2 Life cycle stage and system boundaries

2.3 Output module

The output module quantifies the environmental and economic impacts of the TMH over its multi-cycle. Because of the intricacy of multiple factors, solely computing performance is meaningless. As a result, appropriate weights were allocated to each criterion, and the results were aggregated into a single index using the data normalization process, yielding the 'Sustainability Index.' This process could help prevent contradictory conclusions arising from the economic and environmental analysis (Silvestre et al., 2013).

3. Multi-life cycle assessment

MLCA calculations will be developed based on previous standards and research (de Wolf et al., 2020; PAS 2050: 2011, 2012; van Stijn et al., 2021) by (a) dividing the processes into sub-processes, (b) expanding the system boundary to multiple life cycles, (c) allocating the environmental loads and gains between cycles, and (d) accounting for material degradation in future life cycles. The sum of the environmental impacts of structural systems and building services throughout several life cycles will be used to assess the total environmental impact of a modular unit. The environmental benefits of relocation and reuse will be ascribed to the life cycle after that. The following equations show a simplified mathematical description of the proposed MLCA framework. Equation 1 illustrates the carbon emissions produced by the first life cycle, which combines the impacts of production, on-site assembly, repair, disposal, and recycling.

$$En_1 = En_{P1} + En_{O1} + En_{U1} + En_{D1} + En_{Rec1} \quad \textbf{(1)}$$

Where: In the first life cycle. En_{P1} is the total environmental load of production; En_{O1} is the total environmental load of on-site assembly; En_{U1} is the total environmental load of repair; En_{D1} is the total environmental load of disposal; En_{Rec1} is the net environmental impact of recycling.

As to the intermediate life cycle, the carbon emissions incorporate modular reuse, on-site re-assembly, repair, disposal, and recycling, as depicted in Equation 2. In the intermediate stage, the components' reusability levels will be considered in modular reuse En_{rusi}. The reusability of modular unit components will be decided by (i) material lifespan and (ii) material quality loss, and this will be considered in the environmental impacts of modular reuse. The technical lifespan or functional lifespan of a substance determines its lifespan. Some obsolete materials, such as fireproofing boards, will be replaced by new ones as their technological lifespans approach. Some deteriorating materials, such as beam-column connectors, may require removal from whole modular units. Besides, the incompatible modular design with the new site layout may impact the functional lifespan. As a result of this effect, incompatible modular modules may be discarded.

$$En_i = En_{rus,i} + En_{Oi} + En_{Ui} + En_{Di} + En_{rec,i} \quad \textbf{(2)}$$

Where: In the intermediate life cycles. En_{rusi} is the total environmental load of modular reuse; En_{Oi} is the total environmental load of on-site assembly; En_{Ui} is the total environmental load of repair; En_{Di} is the total environmental load of disposal; En_{Reci} is the net environmental impact of recycling.

In the last life cycle, all the materials are recovered, recycled, reused, or landfilled. The total emissions are shown in Equation 3, which combines the impacts of modular reuse, on-site re-assembly, repair, disposal, and recycling.

$$En_l = En_{rus,l} + En_{Ol} + En_{Ul} + En_{Dl} + En_{rec,l} \quad \textbf{(3)}$$

Where: In the last life cycle. En_{Pl} is the total environmental load of production; En_{Ol} is the total environmental load of on-site assembly; En_{Ul} is the total environmental load of repair; En_{Dl} is the total environmental load of disposal; En_{Recl} is the net environmental impact of recycling.

4. Multi-life cycle costing

The sum of structural systems and building services expenses throughout multiple life cycles will be used to calculate the total economic impact. The economic benefits and costs of relocation and reuse will be attributed to the next life cycle. Throughout the return on investment period, time value and discount rates will be examined for multiple life cycles (Wouterszoon Jansen et al., 2020). Economic factors like the cost of carbon and life cycle will be added to building sustainability assessments for TMH. It is technically impossible to achieve 100% material recycling or relocation of TMH. In this study, TMH deconstruction refers to relocation, recycling, and disposal. Deconstruction expenses, value-added, carbon emissions, and carbon footprint savings will be utilized to determine economic viability. More specifically, the value gained from relocation and the resale value of recycled materials will be subtracted from the total costs associated with disposal, recycling, and relocation, which includes transportation and handling costs, to determine the economic sustainability of TMH deconstruction. Equation 4 depicts the overall cost generated by the first life cycle, which includes costs for production, on-site assembly, repair, and disposal. The resale value of recycled materials will be deducted from the total costs in the initial cycle.

$$Ec_1 = Ec_{P1} + Ec_{O1} + Ec_{U1} + Ec_{D1} - Ec_{Rec1} \quad \textbf{(4)}$$

Where: Ec_{p1} is the total cost of production; Ec_{o1} is the total cost of on-site assembly; Ec_{U1} is the total cost of repair; Ec_{D1} is the total cost of disposal; En_{Rec1} is the gained value produced from material recycling.

Time is an important consideration in any cost model or economic framework. If the relationship of time-value is neglected, cost reduction, regardless of when it occurs, would seem to have higher cost alternatives. As a result, all costs in the MLCC framework should be calculated at the present value (PV) because stakeholders use different discount rates defined for each stakeholder. In the current study, most housing units could be kept reusing during the intermediate life cycle. The future costing will be converted to the PV. The total cost of each intermediate cycle could be computed by Equation 5, which includes the expenses of replacing broken housing units, re-assembling modules, repair and maintenance, and disposal. The value acquired through resale material will also be subtracted from the total cost.

$$Ec_i = \frac{(Ec_{rusi} + Ec_{rei} + Ec_{Ui} + Ec_{Di} - Ec_{Reci})}{(1+i)^t} \quad \textbf{(5)}$$

Where: Ec_{rusi} is the cost of replacement of broken housing module; Ec_{o1} is the cost of re-assembly; Ec_{Ui} is the total cost of repair and maintenance; Ec_{Di} is the cost of disposal; En_{Reci} is the gained value produced from material recycling. i represent the discount rate, and t indicates the time in years.

All materials and modular housing will be deconstructed and disposed of at the end of the life cycle. Similarly, the final life cycle's overall cost can be evaluated using Equation 6, which incorporates the expenses of replacing broken housing units, re-assembling housing modules, repair and maintenance, and disposal.

$$Ec_l = \frac{(Ec_{rusl} + Ec_{rel} + Ec_{Ul} + Ec_{Dl} - Ec_{Recl})}{(1+i)^t} \quad \textbf{(6)}$$

Where: Ec_{rusl} is the cost of replacement of broken housing module; Ec_{ol} is the cost of re-assembly; Ec_{Ul} is the total cost of repair and maintenance; Ec_{Dl} is the cost of disposal; En_{Recl} is the gained value produced from material recycling. i represent the discount rate, and t indicates the time in years.

5. Sustainability index

In order to create a single and comparable number, deconstruction's environmental costs and benefits will be turned into an economic unit. This research used a shadow price method, which unites all category indicators into a single sustainability index. Carbon costs will be calculated using a predetermined carbon value. These factors are related to the cost of carbon emissions that the public pays for, such as the loss of property due to the rise of sea level. This procedure may help in avoiding contradicting outcomes from economic and environmental assessments. The integrated sustainability index SI is calculated below (Equation 7).

$$\mathrm{SI} = Ec_{total} + En_{total} \times u_{cp} \quad \textbf{(7)}$$

Where: Ec_{total} is the cost of the whole TMB life cycle, En_{total} is the total carbon emissions, u_{cp} is the unit price of carbon emissions.

6. Conclusion

The need for TMH is quickly becoming a trend as building stakeholders become more aware of the advantages of sustainable construction. The research first updates and improves the existing LCA and LCC methodology that overcome multiple life cycle challenges. Although still in the conceptual stage, implementing the proposed framework will support multi-aspect evaluation for TMH across its whole life cycle and assist in achieving a higher level of TMH circularity. With the help of this innovative method, professionals will be able to monitor the long-term environmental and economic impacts of modular housing throughout multiple life cycles. In the future, we can Incorporate a larger range of sustainability standards, including some for social sustainability indicators, which will expand the framework's functionality. The suggested MLCA and MLCC frameworks can also be tested on various buildings to ensure their robustness and validity. By doing so, the proposed MLCA and MLCC methods may help the global development of LCA and LCC standards by incorporating important methodological aspects concerning multiple life cycles. This study will promote regional and international standard and practice reforms in the building sector to promote sustainable multiple life cycle management.

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Evaluating Training and Development Features of Human Resource Management Practices in the Nigerian Construction Industry

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Abstract: The construction industry depends on the combined efforts of various individuals or human resources (HRs) who are closely associated to the firms' productivity and performance. To maintain a necessary competence in the HRs, effective training and development human resource management practices (HRMPs) for HRs become imperative. Therefore, this study assessed training and development (TND) features of HRMPs in Nigeria with a view to improving HRs activities in the construction industry (CI) as well as analytically influencing their performance. The study employed a quantitative research approach using Delphi and questionnaire approaches for data analysis. The Delphi study was used to determine the influence of the identified TND features of HRMPs, and data retrieved were analysed using mean item score (MIS). Findings from the study revealed that out of the twenty-one (21) TND attributes evaluated, acquiring new skills and knowledge as well as the usage were ranked high among the TND attributes for HRMPs. Hence, the study recommended adequate usage on newly acquired skills and knowledge of HRMPs by CPs and HRs for greater productivity and performance.

Keywords: Construction Industry, Human Resource Management Practices, Training and Development, Delphi Study, Skills and Knowledge

1. Introduction

Construction contracting is regarded as a very competitive business in the industry. To gain competitiveness, HRs in an organisation need to update their skills, knowledge and required capacity and perceived organisational performance (Naveed, Adnan, Ullah & Sohail, 2017). This could be achieved through TND that constitute the subsystem within the broad spectrum of the personnel function (Kadiresan, Selamat, Selladurai, Ramendran & Mohamed, 2015). TND is one of the factors of HRMPs influencing HRs and organisational performance for strategic goals (Zainon, Ismail, Ahmad, Shafi, Misman, Nawi & Kadir, 2020; Babalola & Aigbavboa, 2022). According to Kadiresan et al. (2015); Ameh and Daniel (2017), training is a systematic development of knowledge, skills and abilities that guides worker's behaviour and attitudes in line with organisational objectives, that brings about HRs performance. On the other hand, development involves planning and preparing HRs for future changes in relation to an unfamiliar jobs and responsibilities (Kadiresan et al., 2015). TND significantly improves HRs and organisational performance (Zainon et al., 2020). TND benefits HRs in relation to better position and better career life (Shafiq & Hamza, 2017).

Studies carried out by Wulandari, Maharani, Young and Winoto (2020) and Zainon et al. (2020) show that providing employees TND programmes, on-the-job training, apprenticeship training, career development, HRs leadership development, coaching, training programmes among other factors are attributes influencing TND of HRMPs in the CI. In response to this, this study reviewed previous literature on attributes of TND of HRMPs in the NCI. The outcome of this study will be of great importance to CPs and HRs by increasing their capability in their assigned tasks or responsibilities. Therefore, this paper is divided into sections including the TND features of HRMPs, methodology, discussion of findings and research conclusion.

2. Training and Development Features of Human Resource Management Practices

To maintain a necessary competence in the HRs, combined efforts of varied individuals are imperious, thus suggesting the need for effective HRs training and development. TND of the HRs depends on /influenced by different factors. However, the training and development factors are activities undertaken by HR to determine their capability in their assigned tasks efficiently and effectively (Kadiresan et al., 2015). In this study, TND referred to processes of bridging gaps between current and desired performance and acquiring additional knowledge beyond employees' current jobs to optimize performance and gain a competitive advantage. TND measures vary from one firm to another. According to Jalil, Shaikh and & Alam (2014); Wulandari et al. (2020), the TND factors influencing HRMPs in Nigeria is the use of on-the-job training method. Organisation should understand that incurring additional cost on training new staff can be offset by encouraging job rotation and mentoring by experienced employee on the job. A study carried out by Boohene & Asuinura, 2011; Jalil et al., 2014 exhibited that the successive are TND attributes of HRMPs: leadership development programmes, employment of newly acquired skills on the job, coaching or supervisor training, and mentoring.

Based on the assertion of Alzyoud (2018), Gope, Elia and Passiante (2018), and Hee and Jing (2018), the TND of HRMPs is influenced by exposure to new knowledge and skills. Through training, HRs prepare for a new skills and additional knowledge that enhances development for future assignment. Likewise, it was revealed that exposure to new knowledge and skills are among TND attributes (Alzyoud, 2018, Gope et al., 2018, Hee & Jing, 2018). A study carried out by Meyer and Smith (2000) and Amin, Ismail, Rasid and Selemani (2014) highlighted measure to include training programmes. Accordingly, other factors as highlighted include investment in the workforce and timely training (Hee & Jing, 2018), career development (Gope et al., 2018; Zainon et al., 2020), and continuous training (Boohene & Asuinura, 2011; Gope et al. 2018) were mentioned as specific variables of training and development. Likewise, a number of other factors for TND that are considered to enhance HR performance and productivity were mentioned as distance training method, job rotation, technical training, and breakout meetings (Gope et al., 2018).

3. Methodology

The features of TND of HRMPs in the Nigerian construction industry (NCI) were assessed using a mixed method research design. The literature review assisted in identifying the TND features which necessitated a qualitative assessment (Delphi study) of these features' suitability to the NCI. The Delphi survey was conducted among fifteen (15) experts, including professionals such as engineers (4), builders (2), project managers (2), architects (2), quantity surveyors (2) in the built environment, and the HR/personnel managers (3) in the NCI. The experts were selected from across Southwest cities in Nigeria; Lagos (5), Osun (1), Ogun (2), Ondo (4), Oyo (1) states including the Federal Capital Territory (2). This assist in enriching the study by seeking varied opinions and knowledge across these cities in Nigeria. According to Mazzucca, Weatherly, Morshed and Tabak (2018); Babalola and Aigbavboa (2022), the Delphi survey is a method that involves the use of a copy of sets of questionnaires to gain consensus and produce feedback to participants who are experts in key areas. It is also based on a group rather than individual judgment (Ameyaw, Hu, Shan, Chan & Le, 2016). These experts are selected based on the following requirements among others: must be knowledgeable in the field of construction/ project management, HRM and its practices; should possess at least a national diploma, a higher national diploma, a postgraduate diploma, a bachelor's degree, a master's degree or doctorate.

The Delphi was conducted over two rounds. In the first round, only closed-ended questions were used in the Delphi study. The responses from round one of the Delphi were analyzed, and the results formed the basis of round two. In the second round, the Delphi questions allowed the expert panelists to review and comment on TND features of HRMPs in the NCI, which the expert panelists proposed in round one of the Delphi study. In the second round of the Delphi study, open-ended questions were used to investigate the expert panelists' comments expressing agreement, disagreement, or clarification concerning proposed TND features that determine HRMPs in the NCI. In both rounds, median and interquartile deviation (IQD) were used to determine the degree of consensus amongst the expert panelists' responses. For each response, the group median was calculated. The group median was the appropriate measure of central tendency utilized in this study because it was found to be more suitable for the type of information collected. The results from the first round Delphi survey formed the second and final survey round questions. Hence, in the second round of the survey, the group median for each element was computed and sent back to expert panelists; they were asked to maintain the first-round response or change it as informed by the group median of the first round. In all, fifteen (15) experts completed two rounds of the Delphi process as against nineteen (19) that started the Delphi survey. The size of the experts was sufficient based on the recommendations from scholars who have previously employed the Delphi techniques in previous studies (Delbecq, Van de Ven & Gustafson, 1975; Aigbavboa, 2013, Babalola, 2023). The experts' opinions were analysed using Microsoft Excel and calculated using the median, mean, standard deviation, and interquartile deviation with the adopted scale for measuring consensus (Aigbavboa, 2013). The experts' credentials were kept confidential throughout the study. Both rounds of the Delphi established twenty-one (21) features of TND out of twenty-six (26) pertinent identified from literature to the NCI.

For the second part of the analysis, a quantitative research approach was adopted because of the study flexibility in relation to data collection through quantitative methods that can be statistically analysed to generalise both explicit and implicit claims (Creswell, 2013). The questionnaire was developed based on the valuation from the Delphi study (qualitative strand). The questionnaire was administered amongst HRs and construction professionals (CPs) in Lagos state, Nigeria. This helps to create a balance between HRs and CPs result in the Delphi study. This study deployed the convenience sampling technique. This was utilised based on the study peculiarity, population, cost and time limitations. The targeted respondents were architects, engineers, builders, quantity surveyors, personal mangers (HRs), project manager in Lagos state. Lagos state was considered ideal because of its proximity and possession of both human and material characteristics pertinent for this study. A total of two hundred and fifty-five (255) copies of a closed-ended questionnaire were distributed to the target professionals in contracting firms, consulting firms, government agencies, and academia. One hundred and seventy-two (172) copies of the questionnaire were returned, representing 67.5% response rate. The google form was utilised through the snowball technique to reach a larger part of the sample within the shortest time and convenience. The retrieved questionnaire was screened and cleaned to confirm their fittingness for analysis and show that the 172 responses were suitable. The questionnaire is made up of two sections. Section A assessed the respondents' background information to ascertain the level of their suitability for the study. Section B evaluated the level of influence TND features have on HRMPs on a 5-point Likert scale, ranging from 5- very high influence to 1- no influence. Before the commencement of the analysis, the research data gathered were cleaned and screened. The frequency analysis for the raw data was achieved using Statistical Package for Social Sciences (SPSS version 27). Also, the mean item score was used to show the outcomes for Likert questions. This was done by calculating the sum of all weighted responses on specific aspects. This was based on the claim that respondents' scores on the whole selected standards are the empirically decided indices of relative importance. The background information was analysed using descriptive statistics and ranked the TND features in the order of which they influence HRMPs and presented in Table format as depicted in the discussion section of this study.

4. Findings and Discussion

4.1. Demographic information of the respondents

Table 1: Respondent and company demographic characteristics

Characteristics	Attributes	Frequency	Percentage
	Male	155	90.0
Gender	Female	17	10.0
	N	**172**	**100.0**
	OND	5	3.0
Level of education	HND	10	6.0
	PGD	18	10.0
	Bachelor's degree	45	26.0
	Master's degree	88	52.0

	Doctorate	6	3.0
	N	**172**	**100.0**
	Engineer	53	26.0
Current profession	Architect	29	17.0
	Builder	32	23.0
	HR/Personnel manager	17	10.0
	Quantity surveyor	22	13.0
	Project manager	19	11.0
	N	**172**	**100.0**
	Less than 12 months	10	5.8
Years of experience	1-5 years	13	7.5
	6-10 years	15	8.7
	11-15 years	39	22.7
	16-20 years	45	26.2
	Above 20 years	50	29.1
	N	**172**	**100.0**
	Contracting firm	20	11.6
Organisation's status	Construction firm	89	51.7
	Consulting firm	13	7.6
	Government	40	23.3
	Consortium	10	5.8
	N	**172**	**100.0**
	General construction works	29	16.9
Business specialization	Building and civil works	60	34.9
	Road works	58	33.7
	Maintenance works	15	8.7
	Other	10	5.8
	N	**172**	**100.0**

Gender, level of education, current profession, year of work experience, organisation specialisation, and type of organisation status in the construction industry are the specific demographic characteristics of respondents analysed under this section. Gender analysis in this study showed that 90.0% of the respondents are males and 10.0% are females. The finding is in line with the work of Babalola and Ojo (2016) that revealed that the number of men in construction works is more than women. Also, the analysis indicates that 51.7% of the total respondents make up the respondents working in a construction firm. At the same time, those in government agency, contracting, consulting, and consortium firms consist of 23.3%, 11.6%, 7.6%, and 5.8% respectively. Further, analysis of respondents' current profession revealed that the majority (26.0%) of respondents are Engineers, while Builders followed, making up 23.0%, Architect followed, making up 17.0%. Quantity Surveyors came next, followed by Project Manager and personnel manager completing the list at 13.0%, 11.0%, and 10.0% respectively.

Analysis of respondents' level of education revealed that 52.0% of the respondents have master's degrees, followed by 26.0% of the respondents with a bachelor's degree, while Postgraduate Diploma (PGD) followed, making up 10.0%. Higher National Diploma (HND) holders came next, followed by Ph.D., and Ordinary National Diploma (OND) completed the list at 6.0%, 3.0$, 3.0% respectively. Thus, indicating that majority of the respondents are relatively educated. Further analysis showed that 34.9% are engaged in building and civil works, 33.7% are into road works. This is followed by general construction works, maintenance works, and other works, making up 16.9%, 8.7% and 5.8% respectively. The analysis further revealed that only 86.7% of the respondents had above five years of work experience while 13.3% having below five years.

4.2. Delphi study

From Table 2, out of the twenty-eight (28) listed variables for the TND construct, twenty-five (25) of the items had a high impact (HI:7.00-8-99), while three (3) remaining variables scored a medium impact (MI: 3.00-6.99). Conversely, none was found to have a very high impact or not having an impact on the determination of HRMPs. Moreover, the IQD scores revealed that a strong consensus was achieved for twenty-one (21) items as they obtained scores ranging from 0.00 to 1.00. However, an agreement was not reached for seven (7) elements, including the availability of employees' job formal and informal training.

Table 2: Training and Development Attributes

Sub-attributes	**(M)**	**($\bar{x}$)**	**(σx)**	**(IQD)**	**(R)**
Sufficiency of training programmes received	8	7.93	1.22	0.50	1
Use of mentoring	8	7.87	1.88	1.00	2
Exposure to new knowledge	8	7.80	1.82	1.00	3
Employment of newly acquired skills on the job	8	7.73	1.79	1.00	4
Breakaway session / workshop section / breakout meeting	8	7.73	1.71	0.50	4
Timely training	8	7.67	1.76	0.50	6
Availability of training programmes among firms	8	7.67	1.76	0.50	6
Exposure to new skills	8	7.67	1.76	0.50	6
Use of coaching or supervisor training	8	7.67	1.76	0.50	6
Use of technical training	8	7.67	1.76	0.50	6
Use of job rotation	8	7.67	1.76	0.50	6
Use of understudy training method	8	7.67	1.72	1.00	6
Availability of development programmes	8	7.60	1.84	0.50	13
Satisfaction with training programmes	8	7.60	1.76	1.00	13
Appropriate training programmes	8	7.60	1.76	1.00	13
Investment on workforce	8	7.60	1.76	1.00	13
Promote skills development	8	7.60	1.88	1.50	13
Continuous training of employees	8	7.53	2.00	0.00	18
Availability of employees' job formal training	7	6.53	1.41	2.00	18
Use of on-the-job training method	8	7.47	1.77	1.00	20
Use of distance training method	8	7.40	1.84	1.00	21
Promote career development	8	7.33	1.76	1.00	22
Use of apprenticeship	7	6.33	1.63	3.00	22
Use of induction/orientation job training method	6	6.33	1.59	2.50	22
Promote leadership development programmes	8	7.33	1.63	1.00	22
Availability of employees' job informal training	5	6.20	1.82	2.00	26
Feedback on the performance of training programmes	7	6.20	1.90	3.50	26
Use of off-the-job training method	6	6.20	1.70	2.50	26

M = Median, $\bar{x}$ = Mean, σx = Standard deviation, IQD = interquartile deviation, R = $\bar{x}$ ranking

Others include feedback on the performance of training programmes, promoting skills development, use of off-the-job training method, use of apprenticeship, and use of orientation job training method. They obtained an IQD score of 1.50 and above, which was beyond the cut-off (IQD≤1) for the present study. In terms of their respective values for standard deviation (σx), it was revealed that there was inconsistency and variability in the responses of the experts owning to the fact that their respective (σx) values were more than one. In addition, the mean score ranking showed that the sufficiency of training programmes received was ranked first. However, three characteristics were jointly ranked last out of the twenty-eight variables. These include the use of off-the-job training methods, feedback on the performance of training programmes, and availability of employees' job formal training.

4.3. Questionnaire survey

The questionnaire was developed based on the valuation from the Delphi study (Table 2) that revealed a strong consensus for twenty-one (21) items as they obtained scores ranging from 0.00 to 1.00. Respondents ranked TND features to measure their level of importance in influencing effective HRMPs in the NCI. Table 3 presents the importance ranking of twenty-one (21) variables that affect TND in the CI. This was attained on a five-point Likert scale ranging from 1 = 'To no extent' to 5 = 'Very large extent.' Based on the mean item scores (MIS) and the standard deviation scores (SDs), the variables were ranked to ascertain their level of importance. Respondents agree largely that 'usage of newly acquired skill on the job for HRMPs' was very important, hence was ranked first (1st) with MS = 3.50 and SD of 1.053 and followed by 'acquiring new skills for HRMPs' also obtaining a MS =3.49 and SD of 1.037. With a MS of 2.86 and SD of 1.097, the 'use of distance training method' in the NCI was ranked last (21st).

Table 3: Factors affecting training and development in HRMPs

Variables	N	MS	SD	R
Usage of newly acquired skill on the job	172	3.50	1.053	1st
Acquiring new skill	172	3.49	1.037	2nd
Acquiring new knowledge	172	3.43	1.062	3rd
Career development programme for employee	172	3.20	1.096	4th
Training programme which provides satisfaction	172	3.19	1.036	5th
Establishment of training programme	172	3.18	1.135	6th
Appropriate training programme development	172	3.17	1.039	7th
Leadership development programme for HR	172	3.17	1.091	7th
Technical training programme for HR	172	3.15	1.045	9th
Development programme establishment	172	3.14	1.043	10th
Employee continuous training programme	172	3.13	1.049	11th
On-the-job training programme for HR	172	3.12	1.085	12th
Sufficiency in training programme received	172	3.10	1.093	13th
Practice of workshop for HR	172	3.10	1.048	13th
Recognition of timely training programme	172	3.09	1.079	15th
Workforce investment programme	172	3.06	1.100	16th
Coaching or supervisor training programme for HR	172	3.06	1.027	16th
Practice of mentorship programme for HR	172	3.03	1.048	18th
Practice of understudy training method for HR	172	3.02	1.060	19th
Practice of job rotation for HR	172	2.94	0.994	20th
Use of distance training method	172	2.86	1.097	21st

MS- mean score, SD- standard deviation, R- rank

Thus, the results suggest that most of the included factors in Table 3 have a significant effect on HRMPs. These effects are in line with findings claimed in previous studies (Boohene & Asuinura, 2011; Jalil et al., 2014; Hee & Jing, 2018; Wulandari et al., 2020; Zainon et al., 2020). These findings suggest that training and development features are a significant determinant of human resource management practices. Hence, the lower the level of training and development features, the lesser the satisfaction of HR with HRMPs in an organisation. The finding of this study is in line with the work of Boohene and Asuinura (2011); Jalil et al. (2014) who ascertained that newly acquired skills on the job should be employed and implemented by HRs and CFs in the CI. The study finding is also significant in that it exposes CFs and HRs to new knowledge and skills (Alzyoud, 2018; Gope, Elis & Passiante, 2018; Hee & Jing, 2018). The study result also suggests that CPs and HRs career development are significant factors of training and development. The finding of this study also corresponds with the work of Meyer and Smith (2000) and Gunu, Oni, Tsado and Ajayi (2013) who found that satisfaction in training programmes established in an organsation influence the implementation of HRMPs. This finding corroborates the conclusion of Amin et al. (2014), whose study presented a significant relationship between training and development and effective human resource management practices in an organisation.

Findings from the current study strongly correspond with establishing a development programme, implementing a training programme that provides satisfaction, sufficiency in training program received, and appropriate training programme development as found in the previous studies (Gunu et al., 2013; Emeti, 2015). Similarly, Hee and Jing (2018) also reported the corresponding result. They find that the most causative factor of HRMPs regarding training and development is recognition of timely training programme in an organisation. Thus, the findings were significant in that it provides the NCI and stakeholders with the knowledge that training and development are beneficial in influencing effective HRMPs implementation. These findings imply that overall HRMPs is a product of the direct influence of training and development. Hence, the NCI can be enhanced through the improvement of the firm's training and development features, such as usage of newly acquired skills, acquiring new skills and knowledge, the training programmes used by the firm, training program received in the firm, and timely training programmes adopted. Further, the findings will form the basis for future studies relating to TND and HRMPs.

Similarly, it will inform policymakers in the NCI in formulating policies that seek to enhance HRM practices in the CI. Thus, training and development in HRMPs is important to enhance the performance and productivity of HR. Therefore, it can be argued that training and development has a significant relationship with the effectiveness of HRMPs and was found to be statistically significant.

5. Conclusion

The purpose of this study was to evaluate TND features of HRMPs in the NCI. This study outcomes revealed that a strong consensus was achieved for twenty-one (21) items out of the twenty-five (25) as they obtained IQD scores ranging from 0.00 to 1.00. Further, the study specified usage of newly acquired skills on the job, acquiring new skills and knowledge, career development programmes, satisfaction with training programmes among others as the features of TND of HRMPs. However, it can be stated that this study objective has been achieved. It is recommended that CPs and HRs should utilise the newly acquired skills and knowledge on the job so as to increase their capability in their existing and future unfamiliar jobs.

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A Review of Technology Application and Benefits in Comprehensive Facilities Management for Housing Quality Assurance

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Abstract

The role of technology in housing delivery has been highlighted in recent research. This study explored technologies and their benefits to housing quality and delivery, especially during the development and operational stages. A desktop study based on a semi-systematic review from Scopus, Google, Google Scholar, Science Direct and Academic Search Ultimate was employed. Thematic analysis was used to analyse the data to extract relevant information from the sampled studies. The identified technologies used in post-construction (facilities management) processes include building information modelling (BIM), autonomous robots, laser scanning and remote sensors, blockchain, radio frequency identification (RFID) technology, drones and mobile devices. While some challenges to adopting new technologies could be associated with the costs, resistance to change, management capacity, and delays in the process flow, the study revealed that the benefits of adopting technology outweigh the challenges. Such benefits include improved speed, accuracy, consistent and complete data, reduced carbon emission, improved collaboration and efficiency and productivity. The study adds to the knowledge on technology adoption in housing quality management.

Keywords

Buildings, Facilities Management, Housing, Maintenance, Quality, Real Estate, Technology.

1. Introduction

Cities are realizing the need for adequate housing and quality management of existing infrastructure and housing stock. Habitat III in 2016, adopted the New Urban Agenda, requiring 'the promotion of housing policies that support the progressive realization of the right to adequate housing for all' by 2030 (World Economic Forum (WEF), 2019). An estimated three billion people will require adequate and affordable housing by 2030 (United Nations (UN), 2019). Adequate housing is a multi-dimensional concept consisting of elements of the residential environment that are both quantitatively and qualitatively sufficient in meeting users' needs, expectations, and aspirations (Mazur et al., 2022). According to the World Health Organisation's Housing and Health Guidelines, housing can be structurally deficient due to poor construction or maintenance (WHO, 2018). In addition, under the Right to Adequate Housing, housing is not affordable if its costs (including the rent, operation, and maintenance) threaten or compromise the occupants' enjoyment of other human rights (ibid.). This suggests that the adequacy of housing is partly a quality issue. Therefore, in addition to the way housing is constructed, the building materials used, operations, maintenance and management are critical to support habitable housing and contribute to guaranteeing the safety and satisfaction of the housing consumer (Mazur et al., 2022).

In addition to the burden of supplying sufficient housing to clear housing backlogs (over 2 million in South Africa), economies are faced with inadequacy and poor quality or unsustainable housing (Eggers and Moumen, 2013; Fuller Centre, 2014). Poor housing quality results in enormous costs (Rotimi et al., 2015). The impasse of good quality real estate development is evinced in the extant literature, which reveals that the quality of housing delivered globally and in Africa is poor (Iddi et al., 2022). This is partly because of technology-related issues, poor facilities management viz-a-viz poor information flow and collaboration among project teams, and reduced productivity (Zainul Abidin et al. 2013). In South Africa, although there are requirements, regulations and guidelines in terms of national standards and policies set by governments to manage housing quality (for example, the National Housing Act and the National Building Regulations, as well as Agrément Certification), the homes are still poor (WEF, 2019; Iddi et al., 2022). More attention should be paid to the end-user or dweller who experiences the function and performance of the house after building, to ensure satisfaction with housing and built environment quality (Mabasa, 2017). Therefore, the observed trends, demand and complaints regarding poor housing quality give rise to the need to continue to explore ways to improve housing quality and ensure the achievement of real estate development objectives. Further, with urbanization, the demand for mass/social housing, housing estates, and high-rise buildings to accommodate middle and low-income households should match efforts to provide new affordable units and maintain the existing stock (Lai, 2011).

Literature advocates incorporating facilities management processes during the project development and implementation stages (Mewomo et al., 2022). Facilities management processes can identify hazards and reduce the risks of health problems such as lead poisoning, asthma, and unintentional injuries and accidents, thus improving indoor environmental quality and the general state of buildings (Korfmacher and Holt, 2018). Adequate management of workflows, risks and adverse events, training and tracking policies and procedures, and managing corrective actions allows for improved housing quality management (ETQ, 2023). A comprehensive quality management system enables facilities and facilities managers to operate at optimal efficiency while meeting required regulations; thus, facilities are a hidden influence on quality (ibid.). Such functions should therefore be included during the planning, installation and maintenance of services within a building (construction and post-construction processes), a view shared by Mewomo et al. (2022) in their study of public facilities. Olanrele et al. (2014) argued that facilities management can relate to business activities and environment (business/commercial properties) but also residential buildings, especially high rise. Nielsen et al. (2012) advocated attention to facilities management functions in social housing delivery, focussed on process management to improve support for sustainable living. Therefore, facilities management functions are critical in public and private buildings, as this study covers.

In addition, the adoption of innovative technologies can improve housing delivery and management (post-construction) processes. This view was supported in previous studies. For example, Okoro et al. (2020) and Calitz and Wium (2022) investigated the application of technology in facilities management, but with a focus on only BIM. Likewise, Gunasekara et al. (2022) examined the use of blockchain technology for facilities management procurement processes, while Marocco and Garofolo (2021) examined research trends on disruptive technologies in facilities management but focused on BIM and its association with the digital twin.

Therefore, ways to improve the status quo through facilities management, which has received limited attention, warrant consideration. The risk of housing deterioration will continue to increase if innovative solutions are not explored. Therefore, this study's objectives were to explore technologies that can be adopted to improve facilities management processes, their applications and associated benefits. Facilities managers need to embrace digital transformations and adapt new technologies to fulfil organisations' core business requirements (Gunasekara et al., 2022). Staying up to date with the latest technologies enables company growth and increases productivity as cost-effective decisions and faster turnaround are possible.

2. Housing Quality Assessment and Management Systems

Housing is a basic human need, which evolves with time. Changes in housing needs have made it necessary to constantly assess housing quality to ensure that it meets users' needs (Brkanić, 2017). However, quality can be subjective and objective. Housing quality assessments are carried out to maximize design quality, ensure the healthy housing quality of apartments, assess apartment safety, and ensure high indoor thermal and acoustic comfort (Brkanić, 2017). These include various subjective and objective aspects based on various perspectives – end users, experts, clients, and potential buyers. In the US, housing quality has entailed appraisal of structures and apartments, overcrowding and physical neighbourhood environment (Brkanić, 2017), and the impact of structural features and physical amenities (James, 2007). Research among selected countries in EU-OECD, Asia-Pacific, Africa, Latin America and Western Asian viewed housing quality assessments in terms of dwelling size and amenities (Heston, 2018). Research conducted in Croatia assessed housing quality on different aspects including the unit, the building, neighbourhood, and socio-economic criteria such as hazards, size, services, amenities, and condition (Brkanić, 2017).

In South Africa, housing quality has been assessed based on user satisfaction with size, services and amenities (Moolla et al., 2011), as well as client satisfaction (CIDB, 2011). However, it is arguable that user satisfaction is the most important measure of housing quality since the end users have to dwell in the structure and experience the functioning and performance while in use (Brkanić, 2017; Mabasa, 2017). Related to this, service quality (facilities) and the condition of the structure are paramount to ensure user satisfaction (Sibiya, 2018). Value for money, which is the most essential element in residential facilities management, dictates the performance of buildings in economic terms and contributes to the effectiveness of housing schemes (Olanrele et al., 2014). Therefore, attempting to address quality for the consumer should be at the forefront of housing policies. Over the years, effort has been made to address some of these challenges through quality management and assurance.

Quality assurance systems have been the most common forms of quality principles applied to housing projects, including document control, audits, non-conformance tracking, Corrective and Preventive Action (CAPA) and Management Review (Sibiya, 2018). The international standards applied to construction is the ISO 9000 family of standards, which includes technical guides, reports and specifications related to quality management systema (Letsbuild, 2020). In the UK, Building Control Bodies ensure that provisions of the Building Regulations are met in all building projects to which the regulations apply, to maintain and improve quality and performance (Baiche et al., 2006). In South Africa, the National Housing Act and the National Building Regulations, as well as Agrement Certification, allow the designs produced by a 'competent person' to be deemed appropriate for a location in terms of health and safety standards (Fuller Centre, 2014; Jackson, 2015). Visible efforts by the government to provide an acceptable level of quality viz-a-viz safety, health and welfare during construction and use of buildings have been made (NHBRC, 2020).

Further, with technological advancement, online systems for quality assessment have been designed and used. For instance, the Housing Quality Indicators (HQI), used in the UK, from 2008 to 2015 for the measurement, evaluation, and improvement of design quality; the Housing Assessment System in Switzerland, developed to aid in the design, evaluation, and comparison of residential buildings (Brkanić, 2017) and the NHBRC's inspection processes during construction in South Africa (NHBRC, 2020). However, more avenues to improve housing quality need to be explored, such as the adoption of technology, especially in the post-construction phase, which receives limited attention in research.

3. Methods

A semi-systematic review in Scopus, Google, Google Scholar, Science Direct and Academic Search Ultimate were used to identify contextual issues regarding housing quality and improvement efforts globally. The search keywords contained keywords including the following, inputted in different permutations: housing, quality, buildings, technology, post-construction, maintenance, and facilities management. The subject areas of Engineering, Environmental Sciences, Business, Management and Accounting and Social Sciences. Most of the articles were focused on inspection and technology use at the maintenance and management stage, construction site management and quality of temporary structures. Some articles contained technology in relation to housing quality and were thus included. Thematic analysis was used to analyse the selected materials. This enabled examining of different researchers' perspectives to highlight similarities and differences regarding technology use in post construction processes (Nowell et al., 2017).

4. Findings

The summary of the study findings is presented in Table 1, covering the technologies identified from the sampled literature, for building and facilities management functions. Their applications in improving operations and maintenance management functions and associated benefits are highlighted and discussed. The table shows that there are ten main technologies, mainly the digital (including the emerging) ones such as augmented reality, digital twin and blockchain technology. The application of these technologies cut across construction and post construction; however, the post-constriction processes are the focus of this paper. The table also covers the benefits which are not limited to improved fast, accuracy, consistent and complete data; reduce carbon emission, improved collaboration, and productivity.

Table 1. Identified technologies, application and benefits in building and facilities management functions

Results	Results	Results	
Autonomous robots	- The autonomous robot is equipped with sensors for navigation, map building, and obstacle avoidance algorithms. - For detection of wall defects - Processes data using computer-vision-based techniques (e.g., using cameras, laser sensors, and infrared thermography (IRT) and codes	- Reduced labour - Improved productivity - Inspection accuracy - Complete data	Wang & Luo (2019) Yan et al. (2018)
BIM, digital twin and augmented reality	- Enables organising of multiple workflows and information - Clear presentation and management of information - Automated spatial data processing workflows	- Complete data - Accuracy - Improved efficiency - Reduces omissions - Easily accessible information - Management of information - Automatically recognise data points - Faster fix	Tang & Pradhan (2012) Kim et al. (2013) Tsai et al. (2014) Ma et al. (2016) Mirshokraei et al. (2019) Kubicki et al. (2019) Khanzadi et al. (2020) Marocco & Garofolo (2021) Sarkar (2021)
Upgrading of software on mobile devices or tablets (eg. Virtual Reality Modelling Language, iObserver Interface, etc.)	- Easy approach to data capturing and inputting information - Automatic generation of observation reports	- Prompt information delivery - Improved efficiency - Increased efficiency	Kim et al. (2013)
Blockchain	Distributed ledger	- Data verification - Ease of data recording, handling and accessibility - Long-term record keeping for maintenance and management	Gunasekara et al. (2022)
Drones and GPS-enabled devices (smartphones and cameras) and network cameras	- Data capture and photogrammetric modelling - uses simple photographs to make intelligent 3D models of objects and structures	- Quick and accurate data capture	Kim et al. (2013) Featherston & Maclachlan (2018) Guyton (2020)
Laser scanning and remote/mobile sensors, eg Lidar	- Data acquisition and post processing	- Data consistency and accuracy - Interoperability	Puente et al. (2013) Yan et al. (2018)
Thermal cameras	- Captures thermal images after heating the assessed environment for a short time	- Data accuracy	Yan et al. (2018)
Radio frequency identification (RFID) technology	- Tracks location and status of hidden components	- Direct visual feedback - Quick data capture	Kim et al. (2013) Li and Burcin Becerik-Gerber (2011)
Wireless routers	- For connectivity	- Improved network and efficiency	Tsai et al. (2014)
Wireless communication devices and programs such as Bluetooth, memory devices and PDAs	- To assist the less skilled	- Improved communication and assistance	Kim et al. (2008) Miller et al. (2016)

4.1 Autonomous Robots

High-quality, complete and more accurate data can be collected with the use of automated data collection systems such as autonomous robots, as opposed to manual inspections (Wang and Luo, 2019). A test performed on a real case study in Budapest, to assess the effectiveness of the BIM system in the recording of building process data revealed improvements in information accessibility, reporting, fault deduction and decision-making (Mirshokraei et al., 2019). With BIM, professionals can import, browse and operate 3D model to help them quickly locate the target and tasks, and generate a plan or standard documentation (Ma et al., 2016). Further, with a corresponding BIM model of the facility to be constructed, a manager can determine all major information, and retrieve them easily offline (Tsai et al., 2014). In addition, the shared environment and update-to-date information provided by BIM is beneficial (Mirshokraei et al., 2019). Similarly, blockchain technology enhances data and information flow, and access for later stages for maintenance and management (Gunasekara et al., 2022).

Furthermore, a robotic system that has the capability of simultaneously assessing different types of defects in constructed buildings such as hollowness, evenness, or cracks can be used (Yan et al., 2018). A thermal camera is used to capture a thermal image after heating the assessed environment for a short time (Yan et al., 2018). However, thermal cameras are ideal for finding objects with a certain temperature, but they do not deliver distance information, while 2D laser scanners deliver distance measurements, and thus a fusion of the two works best (Gleichauf et al., 2017). Other computer-aided applications can be used for facilities management functions (Sarkar, 2021).

4.2 Radio Frequency Identification (RFID) Technology

The findings show that this can be used to locate underground or hidden services on sites and constructed buildings such as utility lines and laid-in pipes. By tracking the location and status of the components, early detection of delays and timely decisions on corrective measures is possible (Li and Burcin Becerik-Gerber, 2011). With the implementation of an RFID-based system, reports are availed to all users and progress of functions can be monitored in real time with reference to specifications (ibid.).

4.3 Wireless and Mobile Computing Devices

Additionally, the findings show that other wireless and mobile computing devices such as routers and editing programs can be useful (Miller et al., 2016). Personal Digital Assistant (PDA) and wireless web-integrated Quality Inspection and Defect Management System (QIDMS) have also been advocated to collect defect data at a site in real time, and effectively manage the status and results of the corrective works (Kim et al., 2008). This view was supported by Marocco and Garofolo (2021) opining that visualisation systems or applications can be utilised to facilitate more effective and efficient processes, and collaborative systems that allow multiple maintenance teams to perform their tasks in real time is desirable.

5. Discussion

Quality control is critical on a construction project as it guarantees compliance with requirements, standards and regulations during and post construction, at least to some extent. Using electronic systems can improve inspections (Sibiya, 2018) which is consistent with the findings of the current study (Table 1). Extant literature discussion the implications of adopting technology in construction and post construction should. For example, in addition to flexibility, improved collaboration and increased productivity (Delaney and D'Agostino, 2015), it can afford benefits such as improved communication and information flow, improved accuracy, reduced costs and time in post construction stages (Delaney and D'Agostino, 2015; Guo et al., 2020; Okoro et al., 2020, Sarkar, 2021).

Adopting new technologies will go a long way in ameliorating the status quo with regard to rate and quality of housing. However, the use of electronic systems, gadgets and new technologies may come with challenges, for example, it may be costly for some organisations to purchase or obtain special licensing, efforts should be made to gradually implement (Okoro et al., 2020). Other challenges in adopting new technologies such as conflicts, management capacity to implement, resistance to change and generational concerns, may also be faced by organisations making the effort (Delaney and D'Agostino, 2015; Marocco and Garofolo, 2021). However, the benefits of adopting new technologies outweighs the challenges. The processes need to be managed in an organisation's work, in the steps of project development, and customised to suit their functions and in line with standard operating procedures (Tsai et al., 2014; Kubicki et al., 2019).

6. Conclusion

The study set out to investigate the technologies for improving facilities management processes, their applications and associated benefits towards housing quality enhancement. New technologies such as BIM, drones and sensors as well as autonomous robots were identified as beneficial. The benefits of adopting these new technologies were also highlighted. These include data consistency and accuracy, time savings, increased efficiency and productivity, better data storage, transfer and management and generally, improved organisational processes. Therefore, adopting these technologies is worth considering given the backlog of housing and the need to deliver on quality.

The findings are envisaged to encourage housing quality assurance entities and managers in devising strategies to adopt new technologies. Policymakers and regulators can consider various technologies to make decisions on which ones will best suit their functions and goals. This is especially important in developing countries where adoption and implementation of various technologies are still developing, and the contexts do not adequately support them. Further studies could be performed on the experiences of real estate professionals in using these technologies to perform specific functions, as well as the wellbeing implication given the interactions between quality environment, people and technology. Also, the factors identified in the current study can be empirically validated through a survey questionnaire and qualitative research methods such as semi-structured interviews can provided a deeper insight into the discourse.

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Health and Safety Management in the Digital Age: Exploring Baneful Elements of Digitalisation

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Abstract

While digital tools have been widely adopted in the construction industry to enhance quality and efficiency, adopting digitalisation for safety and health management has been relatively slow due to uncertainties regarding its potential impact. This paper examines the risks of implementing digital technologies in construction health and safety management. Despite the perceived benefits, digitalisation poses risks such as user error, increasing complexity, reduced interactive relations, information overload, and computer crashes. These risks can compromise the effectiveness and efficiency of construction health and safety management and put personnel working on sites in danger. The study suggests that understanding the different digitalisation risks is crucial for improving health and safety management in construction. Previous studies have focused on the benefits rather than the critical risks of employing digital technologies in construction, resulting in a knowledge gap. Therefore, the study provides empirical evidence on the risks associated with digitalisation to enable construction industry decision-makers to make informed decisions. The study recommends developing measures to reduce uncertainties related to employing digitalisation in construction health and safety. These measures will help overcome the risks associated with digitalisation. The strategies will further enhance construction health and safety practices and ensure that digitalisation yields positive outcomes. The findings of this study will assist construction industry decision-makers in making informed decisions regarding adopting digitalisation for health and safety management. This will help to reduce the uncertainties in return on investment and ensure that digitalisation enhances construction health and safety practices.

Keywords

Digitalisation, Health and Safety, Digitalisation Risks, Digital Tools, Construction Industry.

1. Introduction

Akinshipe, et al. (2022) noted that the world in the past couple of decades has been taken over by digitalisation, and digital technologies and the construction industry are not left out. The implementation of digital technologies has caught much attention in the construction industry to mitigate hazards and unforeseen circumstances to improve health and safety (Nnaji and Karakhan, 2020). Meno (2020) emphatically noted that there had been some progress in using digital tools in the construction industry, especially in developing countries. In the onset, digital technology was largely accepted for raising project quality and increasing overall construction efficiency, which reduced costs and increased profits. However, in recent years several construction safety publications showing a strong trend toward using digital technology to manage safety and health in the construction industry, according to Aghimien et al. (2021) and Nnaji and Karakhan (2020). Even though there is a strong trend toward using digital technologies to manage, there has been some reluctance to adopt new health and safety management methods. This reluctance is a big issue since the traditional methods do not seem effective enough, as evident by the numerous reported construction site accidents (Nnaji and Karakhan, 2020).

The implementation of digital technologies has been said to bring in a lot of benefits. However, Vass and Gustavsson (2017) noted that adopting new methods for site safety management, such as digitalisation, which poses a threat to processes that have worked for years, is frequently regarded as risky within the industry. Previous studies focused more on the benefits rather than the critical risks of employing digital technologies. According to Aghimien et al. (2021), few studies have examined risks related to specific digital technologies. Furthermore, the reluctance to employ digital technologies is because most construction industry decision-makers are unsure of the expected consequences of digitalising health and safety in their companies (Lavikka, 2018). This is where the knowledge gap exists, and this study explored this gap. Understanding the different digitalisation risks and how they can compromise effective and efficient health and safety management in construction will help create room for improvement.

2. Digitalisation Risks in Construction Health and Safety

Previous research has given significant consideration to construction digitisation, and the studies examining the risks associated with digital technologies have yielded clear findings, as noted by Aghimien et al. (2019). These studies indicate that using digital technologies in construction has been associated with negative consequences. According to Nazareno and Schiff (2021), the impact of technology on the workplace is influenced by two interrelated aspects: the content and context of the job. The content of a job includes elements such as the characteristics of major work activities, necessary skills, and the level of autonomy and judgment expected of employees. The context of a job takes into account factors such as the working environment, the social structure of the workplace, the role of an employee within the company, and the type and level of supervision.

In a study on supply chain risks related to the 4IR, Zimmermann et al. (2019) identified several risk factors, including technology inflexibility, an aged production system, increasing complexity, lack of integration with existing IT systems, and insufficient knowledge and skills of key personnel. However, when considering the benefits and drawbacks of different technologies in the workplace, there is also a risk of loss of productivity. Gaille (2016) notes that an overreliance on computers may cause employees or supervisors to neglect their tasks, compromising health and safety in construction. The availability of the internet and access to computers may also lead to distractions such as browsing social media sites, reducing the time spent on actual work tasks and compromising health and safety. In addition, overreliance on computers can lead to work stoppages in the event of a power outage or a sudden system crash, which can jeopardise or compromise operations that depend on the information stored on those computers. Therefore, it is essential to have IT assistants on standby in case of a computer crash.

According to Nazareno and Schiff (2021), implementing new technology in the workplace can significantly impact employee well-being by altering their duties, procedures, and workplace structures. These transitions can lead to psychological stress, which may result in anxiety and mental exhaustion. Such conditions are of particular concern for safety professionals, as they can lead to accidents in industrial operations. Introducing digital tools for managing health and safety may overwhelm managers and workers, compromising their ability to perform their tasks effectively and efficiently. This can also affect productivity levels. Scholars have observed that workers often experience elevated levels of occupational stress and a sense of loss of control or autonomy during technological transition periods (Nazareno and Schiff, 2021). Research on socio-technical systems and the history of technology adoption in the workplace suggests that automation and AI may have complex and mixed effects on well-being, including worker stress, job satisfaction, and overall health.

According to Shahid and Woloszynski (2018), artificial intelligence systems like machine learning rely on appropriate sets of training data to learn and produce correct results. However, when using machine learning for compliance purposes, evaluating whether specific data subject to privacy protection can be used to train AI algorithms and whether AI can use the data to assess compliance is crucial. If the machine learning system learns from biased data, health and safety management may be at high risk of being compromised. Shahid and Woloszynski (2018) warn that adopting machine learning in compliance may take time due to its risks. Similarly, Joshi (2017) stresses the importance of avoiding biases in machine learning systems that may negatively influence decisions. Machine learning in construction can bring benefits, but its implementation could disrupt business operations, jeopardising the management of the health and safety of workers.

Meno (2020) researched technology advancements and found that it results in information overload. As technology becomes more advanced, it generates more information because these technologies collect and make data available faster than the human mind can process. This may disrupt the effectiveness and efficiency of managing health and safety, as keeping up with these digital tools can be challenging due to information overload. Aghimien et al. (2021) also highlighted a danger that construction organisations face when adopting digital solutions: these solutions may not live up to expectations. For example, despite the adoption of BIM, there is still little direct connection between project consultants and subcontractors, leading to organisational silos and poor communication. This can compromise effective health and safety management if there are disruptions in communications between managers.

According to Jónsdóttir and Zahrandik (2017), the increased use of technology due to digitalisation hurts social interactions due to decreased physical contact. This is particularly relevant in the context of health and safety management in construction, where digital tools are used to monitor worksites and train workers, reducing physical interaction between them. As a result, health and safety managers may struggle to balance their roles effectively, compromising the overall effectiveness of health and safety management. Salento (2017) also highlights that digitalisation can affect workers, on-site supervisors and management staff, as it may encourage virtual interactions over physical ones.

According to Bruckmann et al. (2016), safety concerns are a top priority in the construction industry, and potential safety hazards cannot be ignored when humans and robots interact. They explained that digital technologies and automated equipment only run as programmed, so if a safety risk does not meet established standards, the robot will not detect it. This can compromise the health and safety of workers if they rely too heavily on these digital tools and let their guard down. In contrast, humans can naturally adapt to new situations based on their instincts, whereas digital tools are limited by their programming. Hamdi and Leite (2014) also pointed out that there is a lack of trained staff or managers who can effectively handle these digital tools, which can lead to human errors. It is clear that while using digital tools has its benefits, it can also compromise the effectiveness and efficiency of managing health and safety in construction.

Table 1. Risks of digitalising construction health and safety management.

S/N	Digitalisation Risks	Reference
1	Technology inflexibility	Zimmermann, Rosca, Antons, and Bendul (2019)
2	Loss of workforce productivity	Gaille (2016), Aghimien, Aigbavboa, Meno, and Ikuabe (2021)
3	Increasing complexity	Zimmermann, Rosca, Antons, and Bendul (2019)
4	Computer crash	Aghimien, Aigbavboa, and Oke, (2019), Gaille (2016)
5	Impact on well-being	Nazareno, and Schiff (2021)
6	Inconvenient data	Shahid, and Woloszynski (2018)
7	System biases	Joshi (2017)
8	Information overload	Meno (2020)
9	Reduced interactive relations	Zahrandik and Jónsdóttir (2017), Salento (2017)
10	Programming error	Bruckmanna, et al. (2016)
11	User error	Hamdi and Leite (2014)

3. Research Methods

This research is descriptive by design as it examines various digitalisation risks and how they may compromise health and safety management in construction. The survey respondents were all working professionals in the construction industry in South Africa. The study relied on usable survey responses from industry experts retrieved for analysis. In order to quantify the significance of each rating, the five-point scale questionnaire was analysed and transformed into Mean Scores. The validity of the collected data was examined with the help of Cronbach's alpha. With a result of 0.899, it is concluded that the dataset collected was suitable for this study.

All respondents are working professionals from the building sector, with the majority being Quantity Surveyors, Construction managers and Project Managers. Participants also included other built environment professionals who have experience managing construction projects. All study participants possess at least a Bachelor's Degree, with some possessing advanced degrees. Only a small fraction of the group has more than ten years of experience in the field, but the vast majority have between two and ten years. Furthermore, it is essential to note that the engagement sector is fairly evenly split between the public and private sectors and that many participants work in both. The relatively even distribution of respondents enhances the reliability of this study..

4. Results and Discussions

The results of the study present the risks associated with digitalisation that can compromise effective and efficient construction health and safety management. The results indicate that user error is perceived to be the highest risk associated with digitalisation, with an average rating of 4.05 out of 5. The risks perceived as the next most severe are increasing complexity, reduced interactive relations, and information overload, with average ratings of 3.95, 3.94, and 3.90, respectively. The risks perceived as the least severe are loss of workforce productivity and impact on well-being, with average ratings of 3.39 and 3.56, respectively. The standard deviation values suggest some variation in how respondents rated each risk, with computer crashes, programming errors, and system biases having relatively high standard deviations compared to the other risks. Overall, this result provides insights into the perceived risks of digitalisation for construction health and safety management, which can be useful for informing risk management strategies and decision-making in the context of digital transformation.

Table 2. Risks of digitalising construction health and safety management.

Digitalisation Risks	Mean Score	Std Deviation	Rank
User error	4.05	0.858	1
Increasing complexity	3.95	0.931	2
Reduced interactive relations	3.94	0.921	3
Information overload	3.90	0.824	4
Computer crash	3.85	0.956	5
Programming error	3.84	0.909	6
Inconvenient data	3.79	0.926	7
Technology inflexibility	3.73	0.944	8
System biases	3.71	0.876	9
Impact on well-being	3.56	1.050	10
Loss of workforce productivity	3.39	1.030	11

The study's findings support those of Hamdi and Leite (2014), who noted that there is a lack of trained personnel who can handle digital tools. This significantly reveals that human errors can come into play because the staff is not well-trained to manage these digital tools properly. Also, these findings relate to those of Zimmermann et al. (2019), who concluded that the risk factors associated with employing digital technologies include but are not limited to technology inflexibility and increasing complexity. Also, these findings align with those of Jónsdóttir and Zahrandik (2017) as they noted that employing digital tools reduces interactive relations. This is because digital tools encourage them to interact virtually more often, for instance, in the cases of communication and training. The findings on 'information overload' support those of Meno (2020), who noted that technological advancement promotes information overload. Furthermore, these findings support those of Aghimien et al. (2019), who concluded that computers could crash, and a sudden computer crash may jeopardise or compromise many operations that depend on all the information stored on that computer. Also, overreliance on computers can lead to work stoppages in the event of a power outage or computer crash.

Digitalisation is a process of change that aims to improve how things are done. However, changes in operations may not always bring only positive outcomes but can also have negative consequences. There is no doubt that digitalising construction health and safety practices is advantageous. However, according to this study, digitalisation carries risks that may undermine the effectiveness and efficiency of managing construction health and safety. The study identified several risks associated with digitalising health and safety practices. Respondents rated user error, increasing complexity, reduced interactive relations, information overload, and computer crash as the most significant risks. These findings indicate that digitalisation can have a negative impact on managing construction health and safety. For example, if users are not adequately trained to use digital tools, mistakes can be made, compromising health and safety. The study also suggests that digitalisation may complicate things and compromise the efficiency and effectiveness of managing health and safety. Additionally, digital tools are prone to crashing, which can disrupt operations.

5. Conclusion

This study assessed how digitalisation risks could compromise the effectiveness and efficiency of managing construction health and safety. The literature review revealed that while employing digital tools has its benefits, there are also risks involved that may compromise the effectiveness and efficiency of managing construction health and safety. Empirical results revealed that the following risks are most likely to compromise the effectiveness and efficiency of construction health and safety management: user error, increasing complexity, reduced interactive relations, information overload, and computer crash. Digitalising construction health and safety practices is intended to improve practices and operations; however, it also poses risks that can undermine the effectiveness and efficiency of construction health and safety. In addition, digital tools are more likely to complicate things and make managing health and safety more complex, putting personnel working on sites in danger and compromising the successful completion of the project. This clearly indicates that the impacts of digitalising construction health and safety practices can yield positive or negative outcomes. The study recommends developing measures to overcome uncertainties related to employing digitalisation in construction health and safety to reduce uncertainties in return on investment. The study also suggests developing strategies to address digitalisation. These strategies will ensure that digitalisation effectively improves construction health and safety practices.

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A Comparative Study of Green and Living Buildings

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Abstract

Aim and Objective - Buildings are one of the critical components of the built environment in which every aspect of the building's design and construction will impact the wellbeing of its occupants - how it is built, from which material, the outputs of its usage, and the impact on its surrounding ecosystem. The fast pace of urbanization growth across the globe is resulting into environmental issues such as air pollution, heat, water pollution, noise pollution, waste disposal, social and economic problems. To combat such challenges, the concepts of green and living buildings emerged. This paper covers a comparative analysis of green versus living buildings (in pre-construction, construction, and the post-construction stages).

Design/methodology/approach – The paper provides a summary of the systematic review and critical assessment of literature content using secondary data of studies' findings and systematic database searching techniques. This systematic review only includes peer-reviewed, published journal articles. The report summarizes the results of a comprehensive examination and critical assessment of the relevant literature.

Findings – In this paper results indicated that the green and living buildings concepts are indeed similar in certain aspects but also different in all three stages (1) pre-construction (2) construction) (3) post construction. The study also demonstrates that the built environment is heading towards more living buildings than green buildings for a sustainable environment.

Recommendations for Future Research – There is a potential of further research in the living building in particular, with in-depth analysis and assessments for key strategies such as the pre-construction ecology of the place, construction approach strategy, and post-construction facility management, rather than holistic comparisons. Moreover, more studies devoted to material selection and end-of-life challenges, finding eco-friendly construction materials in developing markets, and how can policy makers provide legislative frameworks for the development of green and living buildings in the urban planning process would be a useful addition to the body of knowledge.

Paper type – Research paper

Keywords

Living Buildings, Green Building, Systematic Review, Comparative Study, Sustainable Construction

1. Introduction

Green buildings are becoming increasingly popular and more evident in developed countries. The term 'green' building refers to the use of environmentally friendly techniques and technology in the design and construction of the built environment (Shams & Rahman, 2017). They deal with ecological issues within or outside the building premises to protect the environment (de Ridder & Vrijhoef, 2008). It is crucial for the human race and the planet's living creatures especially that with the pace of urbanization that generate large quantities of waste (Seider, 2017) and scarcity of resources on earth, green architecture and building is a necessity (Robertson, Franzel, & Marie, 2017). Green Living by ensuring any human actions or activities result in positive impact on planet Earth for future generations to live in without the harmful environmental pollutants and emissions is a responsibility of all inhabitants (Rao, Schreiber, & Lee, 2017). While the Living buildings concept is a newly adopted approach to the design, build and management of buildings, aiming to shift the conventional demand driven supply to an inclusive supply driven demand. This is mainly through developing and delivery a building that is resilient to the ever-changing technology, legislations, regulations and stakeholder demands (Ragheba, El-Shimy, & Ragheb, 2016). However, this paper investigates the legitimacy of the hypothesis living buildings being different from green buildings by providing a comparison to each stage of the building life cycle (1) pre-construction (2) construction (3) post-construction.

Definition of a Green Building

The goal of a Green building is to take responsibility for achieving energy and resource efficiency, realizing long-term economic, environmental, and social health. The terms green building and sustainable construction are sometimes used interchangeably. However, the term sustainable construction is applied from the period of pre-construction to the disposal of the building and focuses on the ecological, social, and economic issues involved with a building. Hence, green building is an integral part of the sustainable construction (Shams & Rahman, 2017). The Green building concept is part of green urban infrastructure classified as an approach towards land use that is strategically planned and designed network of natural and semi-natural areas joined with other environmental features that allows for an ideal ecosystem within an urban area that resolves the current challenges encountered (Vrijhoef & de Ridder , 2007). In UAE, "Green building is the practice of creating a built environment that is resource efficient in terms of energy, water, and materials whilst reducing building-related impacts on human health and the environment throughout the building's lifecycle, through better siting, design, construction, operation, maintenance, change of use and deconstruction" (Prosser, Spisak, & Jose, 2021). Their definition is further aligned with the definition of the Environmental Protection Agency (EPA) which defines Green buildings as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction". This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or 'high performance' building (Phillips & Barker, 2021). Additionally, Green Building as any class of building use that relate to the conscientious handling of its surrounding natural resources and causes little interference to its surrounding environment and use environment-friendly material (Lydon, et al., 2017).

Definition of a Living Building

According to (Lootah, 2011), a building is considered 'Living' when it accomplishes certain requirements such as generating its own energy on-site through renewable sources, seizes and treats its own water, be built from non-toxic and environmental-friendly construction materials, uses brownfields yet remains inspirational to live in by interacting and adapting to external stimuli. The living building is a philosophy that bridges the gap between natural and artificial environments by adopting living building strategies integrated in the building's design, construction, renovation and deconstruction (Refer to tables 3-5 below). The urgency to also increase the performance of buildings has demanded for the adoption of the 'Living Building' concept that stresses on the need for good design, fit for purpose, up-to-date technologically, and altering the way we build increasing the benefits of those buildings to both the developers, end-clients and societies by offering both integrated and sustainable products and life cycle service (Hwang, Zhu, Wang, & Cheong, 2017).

2. Methods

The paper provides a summary of the systematic review and critical assessment of literature content using secondary data of studies' findings and systematic database searching techniques. This systematic review only includes peer-reviewed, published journal articles. The report summarizes the results of a comprehensive examination and critical assessment of the relevant literature.

3. Results

3. 1 Benefits of Green Buildings versus Living Buildings

Green buildings have environmental, economic, and social benefits to key stakeholders. They can bring about energy and water savings, which lower operating costs. Moreover, provide the comfortable environment that can improve social benefits, including the increase in occupants' satisfaction due to the positive impact on their health and productivity (Howe, 2010). Additionally, green buildings lead to enhanced wellbeing, physical, psychological and social health, improved livability due to enhanced amenities with easier maintenance, efficient technologies, improved indoor air quality and reduced noise pollution, less urban heat impact due to more shading and protection techniques from extreme weather. Moreover, enhanced storm water management, water quality and efficiency, groundwater recharge, soil infiltration, enhanced property value and return-on-investment, energy efficiency and savings, healthcare savings and overall ecosystem services. Furthermore, organic and local food production, healthy urban ecology-conserving and efficient use of resources, water and assets (Vrijhoef & de Ridder , 2007), (Hegazy, Seddik, & Ibrahim, 2017). Living buildings (1) improve and protect biodiversity and ecosystems (2) improve air and water quality (3) minimize waste streams (4) preserve and restore natural resources (5) minimizes operating expenditure (6) create markets for green services and products especially real estate assets (7) improve the productivity levels of living building occupants (8) enhance the buildings performance throughout its life cycle (9) elevate the comfort and health levels of occupants (10) increase the esthetical qualities (11) reduce the stress on the existing local infrastructure (12) improve the overall quality of life of humans (Lootah, 2011).

The main components for achieving green building as per (Elshimy, Radwan, Kashyout, & Ashour, 2015), (Duijzera, van Jaarsveld, & Dekker, 2018), (Vrijhoef & de Ridder , 2007) are the following:

Site Selection: the green building must be developed on suitable, thoughtful and efficient sites. It must be located away from wetlands and prefer on brown field sites where usually have infrastructure in place. Choosing a site for people who can use public transportation and bicycles to work, preserve open space, manage stormwater, lessen urban heat island effect, decrease light pollution of the night sky. and minimize parking lots to enhance car-sharing which also lead to decrease emission and reduce the use of gasoline Choosing a proper site will help in reducing environmental impact and enhance the energy performance of new buildings (Dakkak, 2021).

Energy Efficiency: the energy efficiency is an important component in most green building projects. Reducing the energy usage in the green buildings around 20% below the usage of the normal building. A proper selection of energy elements, implement envelope air sealing, duct sealing, appropriate placement of air and vapor blocks, decrease the use of harmful chemicals in building refrigeration and air-conditioning systems will enhance the energy efficiency building and maximizing the use of renewable and green energy (such as solar energy and wind turbines) and minimizing the use of fossil fuels (Bronstein, 2019).

Water Efficiency and Conservation: Green building emphasis on conserving water both indoor and outdoor through controlling and reducing the usage of potable water for landscape irrigation and for building, treating the wastewater on site, and use water-conserving fittings inside the building, to lessen water demand. Moreover, current researches have shown the natural processes can be a very effective methods of filtering and separating contaminants from storm water and waste water which can be reused for irrigation and other purposes (Bauer, Mosle, & Schwarz, 2007).

Materials and Resources: A successful green building selects a proper material/product/system during the design phase-the time. Green building materials cover a massive area of themes and materials, and they are well known as ecofriendly and renewable resources. Some of the effective practices followed are assigning permanent locations for recycling bins in the building, using recycled materials such as recycled concrete, dry wall, fly ash from coal- fired plants and newspapers, use renewable, sustainable materials such as bamboo, cork, linoleum, wheat board or straw board cabinetry. Moreover, repairing and reusing of a building instead of demolishing it or constructing new building which has positive impact in environment. Restoration and recycling the existing building components, also helps minimizes any possible negative impact on the environment and protects natural resources, including the raw materials, energy, and water resources which is essential for new construction. It also helps decrease pollution that might happen due to the by-products from manufacturing extraction, and transportation of raw materials, besides minimizing the formation of solid waste that often ends up in landfills (Bahaudin, et al.), (Akshey , Swati, & Disha, 2018).

Indoor Environmental Quality, Safety, Innovation and Integrated Design: The health and productivity of employees and occupants of any building are significantly influenced by the Indoor Environment Quality (IEQ), and recent studies showed the correlation between improved IEQ and occupants' health and well-being. The impact of poor air quality and lighting levels, the growth of molds and bacteria, off-gassing of chemicals from building materials on occupants is significant. One of the main characteristics of green design is to support the well-being of building occupants by reducing indoor air pollution. This can be achieved by selecting materials with low off-gassing potential, proper ventilation strategies, providing suitable access to daylight and views, and providing for best individual comfort controlling through maintaining thermal comfort standards; and offer daylighting and views to the outdoors (Salem, Bakr, & El Sayad, 2018). Innovation is one of the main elements to create a green building design. This includes a variety of ideas, from environmentally friendly technological developments to socially acceptable innovative routes towards green approach. It would be an element to inspire people and professionals to apply green approach during construction phase and it can provide competitiveness in the construction sector. Rapid changes in the economy and high demands for new green construction investments are essential, but the initial high costs slow the progress. A method to measure the annual innovative variation in construction sector is a complex indicator that ranks countries/economies/projects depends on their environment to innovation and the outputs from implementing innovation. This indicator is called global innovation index (Hamad, 2020).

3.2 Criteria of the living building

The Living Building Challenge is a strategy for defending the ecosystems of natural resources that sustain human health. Instead of concentrating on densely connected neighborhoods, it sets a ban on what seems to be endless outward growth. In this situation, living buildings have a special requirement to restore surfaces and natural functions to harmonious built-environment interfaces (Hamad, 2020). It is a philosophy, certification, and advocacy tool for projects to change into regenerative type (WBDG, 2021). The criteria of the living building are as follows:

Limits to growth: buildings are only permitted to be constructed in this situation on ready-made, gray, or abandoned land (Beardsley, 2019) that does not belong to (1) Wetlands: The spots chosen should be at least 15 meters and up to 70 meters apart (2) Primary dunes: At least 40 meters must separate the chosen places. (3) Old growth forest: At least 60 meters must separate the chosen places. (4) Native Prairie: At least 30 meters must separate the chosen places. (5) Prime farmland (6) Within the100-year floodplain (Hamad, 2020).

Urban agriculture, Habitat Exchange and Human-powered living: Floor area ratios should be utilized as a starting point for calculations to calculate the square meters committed to agriculture, and buildings should incorporate agricultural potential appropriate with their size and density. As part of the habitat exchange in this situation, areas of the same size distant from construction sites should be permanently set aside (Hamad, 2020). There is a 0.4 hectare/1.0-acre minimum offset per project. Communities should be made more walkable. For this effort to succeed, the community's ability to support a car-free lifestyle must be improved (Dittrich, 2001). The proposal should demonstrate at least propose a mobility plan that spans both the inside and outside of the building by following (1) considerations for pedestrian walkways, such as weather protection in front of the road; protected parking for human-powered cars; facilities for promoting bicycles (2) choosing steps in buildings over elevators and advocating for good stairs (3) encourage the adoption of transportation powered by people (4) at least one electric vehicle charging station. Communities should encourage residents to use bicycles, public transportation, alternative fuel vehicles, and car sharing to minimize traffic (Beardsley, 2019).

Water: in many nations around the world, the lack of and poor quality of drinkable water has recently become a severe problem. The living building made the case that every structure, piece of infrastructure, and community should be planned according to the carrying capacity of the land: gathering enough water to satisfy the demands of a certain population while honoring the natural hydrology of the land. The cycle of using, cleaning, and reusing water can go on forever. Creative reuse and water saving are essential. Net positive water: Building water should be used and released in accordance with the water flows on the construction site and in the area around it. It should be underlined that all water needed must be obtained naturally, either through the collection of rainfall or other closed-cycle water sources, or through the recycling of water used in the structure (Hamad, 2020). Without the use of chemicals, water should be sufficiently purified. Additionally, all stormwater runoff, including gray and black water, should be treated, and controlled through infiltration or reuse (Beardsley, 2019).

Energy: building orientation, glazing choice, and the use of climate-appropriate building materials are some examples of design features that lower overall energy requirements in a living structure. The energy consumption of a building can be further decreased through passive heating and cooling, as well as natural ventilation with intelligent controls. The production of renewable energy on-site enables the remaining energy needs to be partially satisfied by non-fossil fuel energy, decreasing the need for conventional sources. In this situation, the living building demands a secure, dependable, and decentralized power system that can meet internal and external demand without the drawbacks of fuel combustion. Net positive energy: Net annual energy requirements should be met entirely by on-site renewable energy sources, with no on-site combustion. In this situation, onsite clean energy storage should be utilized for resilience (Beardsley, 2019).

Health and Happiness: the health and comfort of building occupants are protected by good indoor environmental quality in dwelling structures. High-quality indoor settings increase output, raise a building's worth, and lessen owners' and designers' liability (Beardsley, 2019). In this situation, rather than addressing all potential ways that an interior environment could be impaired, the health and happiness petal in the living building challenge concentrates on the fundamental environmental conditions that should exist to generate healthy and highly productive environments (Hamad, 2020). Numerous interior environments are harmful to a person's health and productivity. Because increasing well-being in the physical environment is typically energy intensive, there is a relationship between lower comfort and increased environmental consequences.

Civilized and Health Interior environment: Windows that can be opened and closed to let in natural light and ventilation are required in every occupied section of the building (Beardsley, 2019). Health interior environment requirements should be met by living structures to promote good indoor air quality. Hence, entrances must be provided by a separate entry space with an interior dirt track-in system and an external dirt track-in system. Additionally, each kitchen, restroom, copy room, janitorial closet, and location used to store chemicals must have its own ventilation system that exhausts to the outside air. Furthermore, equipment should be placed to monitor CO2, temperature, and humidity levels, and ventilation rates should be planned to adhere to ASHRAE guidelines. Also, smoking should not be permitted inside the structure and use cleaning supplies bearing the "EPA Design for the Environment" mark (or international equivalent) (Selim, 2007), (Beardsley, 2019).

Biophilic environment: Building design should include elements that support the natural affinity between people and the environment. One of the six recognized biophilic design components must be present on every 2000 square meters of the project. Those components are environmental considerations, organic forms and shapes, patterns and processes found in nature, plenty of space and light, geographically based connections and human-nature interactions have changed over time (Hamad, 2020). The building design plan should include natural components like topography, space, light, and organic shapes and forms. Also, include evolving human-nature connections as well as natural patterns and processes. Furthermore, create ties based on place that connect people to the environment, climate, and culture and lastly, have enough and frequent opportunities for people to interact with nature within and outside the building so that most residents feel a direct connection to it (Davenport, 2019), (Ibrahim, 2020).

Materials: According to the living building challenge, all construction materials should be renewable and have no detrimental effects on ecosystem or human health. The precautionary principle serves as the foundation for all material decisions. The reduction of embodied energy and other effects related to the extraction, processing, transportation, upkeep, and disposal of building materials is the focus of the materials petal in this context. A life-cycle approach to performance and resource efficiency is supported by the requirements (Davenport, 2019), (Ibrahim, 2020).

Red list: The project is not allowed to contain any of the red list substances such as asbestos, cadmium, chlorinated polyethylene and chloro-sulfonated polyethylene, chlorofluorocarbons, chloroprene (Neoprene), formaldehyde (added), halogenated flame retardants, hydrochlorofluorocarbons, lead (added), mercury, petrochemical fertilizers and pesticides, phthalates, polyvinyl chloride, and wood treatments containing creosote, arsenic, or pentachlorophenol (Salem, Bakr, & El Sayad, 2018).

Embodied carbon footprint: The building should account for the overall footprint of embodied carbon (tCO2e) from its construction through a one-time carbon offset related to the building boundaries (Salem, Bakr, & El Sayad, 2018).

Responsible industry: It is important to encourage the extraction of sustainable resources including stone, rock, metal, minerals, and timber using third-party approved standards (Salem, Bakr, & El Sayad, 2018). There must be at least one declared product for every 500 m2 of gross building area. For example, to clear a site for building or to maintain the continuous ecological function, all timber from salvaged sources must be certified to Forest Stewardship Council (FSC) 100% labelling criteria (Salem, Bakr, & El Sayad, 2018). Using resources from the living economy: The structure should include place-based solutions and support the expansion of the local economy by using sustainable procedures, goods, and services. In this situation, the restrictions that should be adhered to are (1) within

500 kilometers of the construction site, at least 20% of the construction expenditure should originate (2) an additional 30% of the budget for construction supplies must originate within 1000 kilometers or even closer to the construction site (3) within 5000 kilometers of the construction location, an additional 25% of the budget for building supplies must originate (4) about 25% of the materials can be sourced from any location (5) the project site must be within 2500 kilometers of the consultants' residences .

Net positive waste: To protect natural resources, net positive waste refers to the decrease or elimination of waste creation during design, building, operation, and end-of-life. In each of the subsequent phases, a Material Conservation Management Plan outlining how the structure maximizes materials should be put into practice at the design phase when parameters for the product should take appropriate durability into mind. At the building stage, which entails waste material collecting and product optimization. Additionally, at the operational phase, which consists of a strategy for gathering consumables and durables. Lastly, at the end-of-life phase, which entails a plan for deconstruction and reusability (Salem, Bakr, & El Sayad, 2018).

Equity: Communities should grant everyone equal access, regardless of their age, physical capabilities, sexual orientation, or socioeconomic background, according to the concept of equity. Human scale + humane places: Instead of being built to an automobile scale, the structure should be constructed to be human scale, fostering culture and social interaction (Hamad, 2020). For design features that contribute to livable spaces, such as paved areas, streets, block design, building scale, and signs, there are maximum and minimum requirements. Universal access to nature and place: All facilities, modes of transportation, roadways, and infrastructure ought to be open to all classes, irrespective of age, social status, economic standing, or even homelessness, to construct a living community (Beardsley, 2019). In this situation, reasonable precautions should be taken to guarantee that everyone benefits from the project and that those with physical disabilities have access to it in a reasonable manner. Additionally, the design should not impede or impair the society or surrounding areas' access to or quality of natural waterways, fresh air, or sunlight (Ibrahim, 2020). The initiative ought to address any noise that the public can hear. Equitable investment: The development must set aside and donate half a cent (or equivalent) or more to a charity of its choice, or contribute to ILFI's Living Equity Exchange Program, which directly funds renewable infrastructure for charitable enterprises. This requirement applies to all construction costs, including land, soft costs, hard costs, and even furniture. The charity needs to be situated in the nation where the project is being undertaken. Just organization: Through the open disclosure of the primary organizations involve business practices, the building should help to create a more JUST, equitable society. As part of ongoing advocacy, project teams are required to send JUST program information to at least ten project consultants, sub-consultants, or product suppliers. At least one project team member (architect, landscape architect, MEP engineer, interior architect, structural engineer, owner, or developer) must have a JUST label for their company (Hamad, 2020).

Beauty: This flower contends that every square meter of building construction ought to be use enhancing people's lives. In this regard, it is necessary to create and coordinate initiatives to inform the public about the advantages of their living building challenge projects in terms of the environment. the importance of beauty as a sign of preservation, conservation, and service to society. Beauty and spirit: The structure must contain elements that enhance human enjoyment as well as the infusion of place, culture, and spirit in accordance with its intended usage (Beardsley, 2019). Inspiration and education: The public should have access to educational materials about how buildings operate and perform to share successful solutions and incite others to make improvements that will result in more living buildings (Salem, Bakr, & El Sayad, 2018). In this situation, buildings should offer every year, a public open house to be held. Secondly, a website dedicated to education that provides details on the planning, building, and maintenance of the structure. Thirdly, a straightforward booklet outlining the project's architecture, the topographies of the surrounding environment, and tips for inhabitants on how to maximize building functionality. Fourthly, a duplicate of the maintenance and operations manual. Fifthly, a signage that provides information about the building to both visitors and tenants. Lastly the website of the institute will publish a case study on living building in addition to, non-sensitive portions of the building ought to be accessible to the public for at least one day a year so that people can interact with it in person.

4. Discussion

Hypothesis Analysis - H1: living buildings are different from green buildings
This section will provide comparative literature that attempts to prove the above-mentioned hypothesis by comparing the validity of this hypothesis from three main elements: (1) Pre-construction (2) Construction (3) Post-construction.

Pre- Construction: Studies that concentrate on life cycle stages other than the use phase have grown in number recently; more study is being done on material selection and end-of-life issues as the potential to reduce environmental impacts from embodied energy of materials is becoming apparent. Embodied energy contributes significantly to a building's life cycle effects and can be decreased in a variety of ways, such as by using eco-friendly materials or taking the goods' useful lives into account. The complicated technologies used in green buildings, such as solar panels and geothermal wells, can occasionally result in an increase in embodied energy. Thus, choosing materials carefully can result in several trade-offs that have been found to have negative building implications. Choosing materials with a reduced toxin level, a greater recycled content, or those that are locally sourced can all potentially have a positive impact on the life cycle of a product. In addition, recycling and reusing reduce the amount of material that is added to both manufacturing processes and waste streams, which reduces the overall life cycle impacts. Materials play a crucial role in the life cycle impacts of buildings, and the USGBC, ILFI, and other green building rating system organizations have recognized this. As a result, additional materials standards have been added to their certifications. There is potential for improvement even though the Living Building Challenge (LBC) is a comprehensive building assessment system. Quantifying material impacts, including material choice and embodied energy, is one topic. One imperative that calls for offsets for the embodied energy of just the construction phase is the only one in LBC 3.1 (2017) that deals with material embodied energy. As was previously mentioned, all other life cycle stages become more significant and warrant more assessment as the usage phase of high-performance buildings shortens, necessitating a more thorough evaluation of building materials to quantify the shifting effect distribution of those phases. The examination of construction material choices, which in this context refers to the steps of material extraction, production and processing, and transportation, should be considered in the planning and design stage of construction. Table 3 in the appendix clearly demonstrates the similarities in the pre-construction stage which can be summarized in the focus on landscape and access to nature, water, energy and carbon reduction whereby the main differences is more focus of living buildings on the ecology of the place of living buildings through numerous additional strategies imposed than in green buildings.

Construction: Living building structures are similar to the living organisms, getting older slowly but rapidly and simply changing on cell level. In construction phase of the living building, instead of the concentrating of extending the lifetime or renovating the whole building, they are focusing on components rather than complete buildings, buildings are considered as a collective of elements with different properties and lifetimes. In this case, a construction work of living building is determined as an intervention in the built environment. An intervention occurs at element, component and is understood by calculating the change in value and the change in costs for the entire system over the design lifetime of these particular components or elements. As per de Ridder and Vrijhoef, the changed value as result of the intervention is subdivided in (1) architectural value (form), (2) functional value (quantity, capacity), (3) technical value (quality) and (4) the extracted value from the world around the building (system). The changed costs consist of: (1) the investment associated with the intervention and, (2) the savings in maintenance and operation due to the intervention over the design lifetime of the changed component or sub- system, so living building are keeping in consideration the value, price and cost as variables which keeps the building up to date with state of art technology unlike the green building where value and price of the building are fixed. Table 4 in the appendix clearly demonstrates the similarities in the construction stage which can be summarized in the focus on healthy interior performance and all projects must connect people with nature in both interior and exterior of the building being constructed whereby the main differences is green building construction explicitly outlines the exact strategies that must be adhered to while the living building construction is more structured and flexible as it recommends strategizing the construction approach from a material, procurement, and environmental friendly project life cycle operation (Hwang, Zhu, Wang, & Cheong, 2017).

Post – Construction: Upon the collection of architect approved as-is built drawings, collection of warranty and maintenance manuals, vendor bill certification, rectification of snags and creation of defect contact list, preparation of completion certification and facilitation of handover to facility management; starts the two main phases to the post construction stage, first is the occupation while the second is the maintenance phase (Virginia's United Land Trusts, 2021). However, historically, considering the building's long-term use and sustainability was not always a core concern during the preconstruction and construction stages. Nowadays the urge is to place a high premium on the building's sustainability in order to control the post-construction costs (Davenport, 2019). Is the post construction phase in living buildings any different from that of green buildings? According to (PWC, 2022), sustainable construction has lower yearly cost for energy, water and maintenance than its non-green counterpart. That is more direct cost saving and financial benefits to the building owners and surrounding as they have 14% less impact on environment due to the reduced Greenhouse Gas Emissions (GHG) (Selim, 2007). However, there were limited studies on whether living buildings are different from sustainable green buildings. Table 5 in the appendix clearly demonstrates that in the post-construction stage the similarities is both type of buildings relying on digitalization and automated monitors to control energy, water, waste, temperature, moisture and ventilation of occupying and maintain both types of buildings however the differences can be summarized in the form of living buildings further demanding strategies on the facility management front.

5. Conclusions

The core finding of this research is that, in the pre-construction stage which can be summarized in the focus on landscape and access to nature, water, energy and carbon reduction whereby the main differences are more focus of living buildings on the ecology of the place of living buildings through numerous additional strategies imposed than in green buildings. The similarities in the construction stage which can be summarized in the focus on healthy interior performance and all projects must connect people with nature in both interior and exterior of the building being constructed whereby the main differences is green building construction explicitly outlines the exact strategies that must be adhered to while the living building construction is more structured and flexible as it recommends strategizing the construction approach from a material, procurement, and environmental friendly project life cycle operation. While in the post-construction stage the similarities are both type of buildings relying on digitalization and automated monitors to control energy, water, waste, temperature, moisture and ventilation of occupying and maintain both types of buildings however the differences can be summarized in the form of living buildings further demanding strategies on the facility management front.

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Appendix

Table 1. Living Building Criteria vs. Greenstar Criteria

Living Building Criteria	Greenstar Criteria
Limits to Growth	Sustainable Sites
Urban Agriculture	Ecological Value
Habitat Exchange	
Human-Powered Living	Sustainable Transport
Net Positive Water	Metering and Monitoring/Potable Water/Stormwater
Net Positive Energy	Metering and Monitoring/Greenhouse Gas Emissions/Peak Electricity
Civilized Environment	Provision of Outdoor Air/Visual Comfort
Healthy Interior Environment	Ventilation System Attributes/Exhaust or Elimination of Pollutants
Biophilic Environment	
Red List	Indoor Pollutants/Responsible Building Materials/Refrigerant Impacts
Embodied Carbon Footprint	Life Cycle Assessment
Responsible Industry	Responsible Building Materials: Timber Products/Sustainable Products
Living Economy Sourcing	
Net Positive Waste	End of Life Waste Performance/Environmental Management Plan
Human Scale + Human Places	
Universal Access to Nature & Place	Innovation Challenge Universal Design
Equitable Investment	Innovation Challenge: Social Enterprise
Just Organizations	
Beauty & Spirit	
Inspiration & Education	

Table 2. Living Building Challenge imperative vs. Innovation Claim in Green Star

Living Building Criteria	Greenstar Criteria
Urban Agriculture	Global Sustainability: Green Star - Communities 'Access to Fresh Food'
Habitat Exchange	Global Sustainability
Net Positive Water	Exceeding Green Star Benchmarks
Net Positive Energy	Exceeding Green Star Benchmarks
Red List	Global Sustainability
Living Economy Sourcing	Innovation Challenge: Local Procurement
Human Scale/Human Places	Global Sustainability
Universal Access to Nature and Place	Innovation Challenge: Universal Design
Equitable Investment	Innovation Challenge: Social Enterprise/Social Return on Investment
Beauty and Spirit	Global Sustainability
Inspiration and Education	Global Sustainability

Table 3. Green Building vs. Living Building Pre-construction Strategies.

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Planning	Preliminary performance targets set by the integrated design team and building owner at the outset of the project; appropriate to the site and program	According to (International Living Future Institute , 2019): S1: Energy (Energy Use, Energy Source, Clean Energy Transport) S2: Water (Water Use, Water Filtration, Ground Water Recharge, Human Waste) S3: Landscape (Integrated Pest Management, Green Space, Native Plantings and Wildlife Habitat) S4: Materials (Recycled Materials, Efficient Materials, Salvaged Materials, Local Materials, Durable and Low Maintenance) S5: Waste (Recycling and Composting Facilities) S6: Construction Practices (Construction Waste, Reuse Topsoil, Vegetation and Watercourse Protection) S7: Indoor Environmental Quality (Air Pollutant Emissions, Ventilation Effectiveness and Air Filtration, System Commissioning and Cleaning, Daylighting) S8: Economic Performance (Life-Cycle Assessment, Capital Cost Accounting)	According to (WBDG, 2021): S1: Ecology of Place S2: Urban Agriculture S3: Habitat Exchange S4: Human-Scaled Living S5: Responsible Water Use S6: Net Positive Water S7: Energy and Carbon Reduction S8: Net Positive Carbon S9: Healthy Interior Environment S10: Healthy Interior Performance S11: Access to Nature S12: Responsible Materials S13: Red Line S14: Responsible Sourcing S15: Living Economy Sourcing S16: Net Positive Waste S17: Universal Access S18: Inclusion S19: Beauty and Biophilia S20: Inspiration and Education
Pre-construction	Planning	Research Funding Opportunities	S1: There are many financial and supporting resources to support green buildings which are to be applied at the initial stages of the project (International Living Future Institute , 2019)	S1: Set a per square foot of the living building project site [27] S2: Offset through land acquired through an accredited land trust, if applicable [27]

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Planning	Start early to source salvaged materials	According to (International Living Future Institute , 2019): S1: Look for appropriate salvageable materials from demolition contractors, specialty suppliers, salvaged building material suppliers, or buildings that are being deconstructed S2: All consultants should be ready to specify salvaged materials, when a source has been specified, the availability, quality of material, timing and storage should be confirmed	According to (WBDG, 2021): S1: use responsible materials as a baseline for all projects which is known as 'responsible materials' S2: Follow 'responsible sourcing' when calculating material requirements S3: Divert within the project 80% of the construction waste material from the landfill and provide dedicated infrastructure for the collection of recyclables and compostable food scraps during occupancy S4: Third-party certified standards for sustainable resource extraction and fair labor practices for all construction material extractions S5: Third-party certified standards for sustainable resource extraction and fair labor practices for all construction material extractions S6: 20% of the materials construction budget come from within 500 kilometers of construction site S7: 30% of the materials construction budget come from within 1000 kilometers of construction site S8: 25% of the materials construction budget come from within 5000 kilometers of construction site while the remaining 25% from any other location

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Planning	Select appropriate land	According to (International Living Future Institute , 2019): S1: The land selected should be of a short walking distance from public transit, pedestrian and bicycle routes, exists in an already-urbanized area, is within walking distance from amenities, is already serviced by the requisite urban infrastructure such as roads/utilities/etc., is a brownfields site to remediate, allows infill development and allows mixed-use development S2: Avoid selecting sites that are flood land, greenfield areas, wetlands, ecologically sensitive land which is a habitat for rare or endangered species, or used as wildlife corridor	S1: include a performance-based approach to the project location, local ecology, and community which is what is known as 'ecology of place' (WBDG, 2021)
Pre-construction	Planning	Selection of the Design Team	According to (International Living Future Institute , 2019): S1: Select a design team with experience or interest in green and integrated design S2: Green design knowledge, skills and experience are criteria for the selection of architects, landscape architects, engineers and other members of the design team S3: Request from all design applicants to provide proof of their knowledge and previous experience with green design principles and practices S4: Ensure that the selected design team members have skills in facilitation, energy simulation, green expertise, value/cost analysis	According to (WBDG, 2021): S1: Consider 'inclusion' and diversity in hiring and provide the team members access to training S2: Consider at least one Living Future Accredited (LFA) subject matter expert in the project team

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Design	Protect or enhance site's ecological integrity and biodiversity	According to (International Living Future Institute , 2019): S1: Minimize the development footprint, cluster buildings together, re-establish damaged native ecosystems, preserve, establish, or re-establish wildlife habitat by providing shade, shelter, food and water to sustain the desired wildlife, pedestrians, cyclists and others S2: Make connections between the natural ecology of the site and natural systems both within and beyond the site S3: Build support for urban greenways that can be used by wildlife, pedestrians, cyclists, and others through working with the relevant local or regional government agencies to help establish, connect with or further develop a greenway	According to (WBDG, 2021): S1: Consider biophilic design for beauty S2: Protect land for other species by setting aside in each project land identical to the project area away from the site
Pre-construction	Design	Reduce or eliminate disturbance to water system	According to (International Living Future Institute , 2019): S1: Minimize storm water runoff by using organic stormwater management features S2: Make natural water management techniques into attractive landscape elements S3: Install oil/water separators to treat run-off from parking lots only and not from fields or roofs S4: Design roads and parking lots without curbs or with curb cuts or openings that drain to stormwater treatment & infiltration measures	S1: Net Positive Water (Lootah, 2011) S2: Divide the water requirements into core and living under what is known as 'the water patel' (WBDG, 2021) S3: Treat water like a precious resource (WBDG, 2021)

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Pre-construction	Design	Prevent or reduce the use of potable water for irrigation	According to (International Living Future Institute , 2019): S1: Harvest rainwater or use recycled storm water, or site-treated grey or waste water for irrigation ° Use water-efficient plants. These are often native species, or species that have adapted ° Use water-efficient irrigation, including: ⇒ micro irrigation ⇒ moisture sensors ⇒ weather data-based controllers	According to (WBDG, 2021): S1: Treat all stormwater on-site without chemical use and based on pre-development hydrology and current ecological conditions S2: Minimize waste and the use of potable water for irrigation • New Building 50% • Exiting Building 30%
Pre-construction	Design	Reduce urban heat islands	According to (International Living Future Institute , 2019): S1: Maximize green space through use of native gardens, trellises, roof gardens S2: Maximize previous surfaces for parking areas, paths, courtyards S3: Use light colored, high-albedo materials for all non-pervious surfaces S4: Drawings and specifications must record expected albedo requirements S5: Provide shade on impervious surfaces where high-albedo materials cannot be used	According to (Lootah, 2011): S1: Net Positive Carbon S2: The generation of renewable energy on the project site allowing for portions of the remaining energy consumption to be met with non-fossil fuel energy
Pre-construction	Design	Design infrastructure to support alternative transportation	According to (International Living Future Institute , 2019): S1: Locate building to have access to public transit, bike routes, and pedestrian routes S2: Encourage walking and bicycling by designing attractive, safe pedestrian and cycling infrastructure S3: Maximize bicycle-parking spaces and minimize car parking spaces S4: Build changing facilities and showers for cyclists and joggers S5: Give preferred parking to carpool cars	According to (WBDG, 2021): S1: Contribute toward the creation of walkable communities that minimizes the usage of fossil fuel vehicles S2: Provide electric vehicle charging stations S3: Provide bike lockers and shower facilities to encourage the use of bikes in the communities S4: Ensure parking larger than 20m x 30m separated with planted areas S5: Enhance pedestrian routes to encourage walking S6: Advocate the use human-powered or public transportation S7: Provide carpool coordination assistance by providing access alternative fuel vehicles

Table 4. Green Building vs. Living Building Pre-construction Strategies.

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Building Orientation and Configuration	According to (International Living Future Institute , 2019): S1: Use existing and proposed trees & plantings S2: Orient the building to optimize prevailing winds and solar opportunities S3: Use existing and proposed topography to create thermal mass around the building S4: Assess the feasibility of using on-site renewable or alternate energy S5: Narrow floor plates can be used to give greater access to daylight, views, and natural ventilation S6: Interior temperature fluctuations can be moderated by thermal mass S7: Computer simulations of thermal massing and natural ventilation strategies can help to assess which strategies save energy and work as designed S8: Reduce heating, cooling, lighting and ventilation loads through careful placing of internal uses S9: Locate internal spaces to optimize natural ventilation, daylighting, and site resources like trees or topography for shading S10: Uses that do not need windows can be located on the north side S11: Create zones S12: Use circulation areas as buffers S13: Be as space efficient as possible S14: The integrated design team should select the best concept design, including the orientation, configuration, massing and siting S15: Finalize all non-energy performance targets	According to (WBDG, 2021): S1: Improve the accessibility to fresh food through the introduction of a secondary path and ensure food storage requirements are considered and design modified accordingly as part of the ‘urban agriculture’ to accommodate at least two-week supply of food S2: Implement a resilience strategy for all projects to provide 75% of emergency supply for occupants up to three days

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Building Systems Design – Structure Design	According to (International Living Future Institute , 2019): S1: Conduct an energy simulation S2: Design with salvaged, recycled and efficient materials as much as possible S3: Use locally harvested or manufactured materials S4: Use materials with low environmental impact over their life S5: Use low-VOC materials S6: Design for flexibility, disassembly and reuse S7: Design building for solar heat and light S8: Control solar heat gain and glare S9: Design building to incorporate the site's wind and air resources S10: Assess the feasibility of incorporating renewable energy into the envelope, using: ⇒ passive solar technologies like solarwall ⇒ active solar technologies like photovoltaic panels S11: Optimize daylighting and views S12: Design the envelope to provide adequate fresh air S13: Set ventilation targets S14: Select an efficient mechanical or natural ventilation system S15: Assess the potential for heat recovery systems S16: Consider using zones to group areas with similar occupancies and ventilation needs S17: Weigh the benefits of VAV (variable air volume) air distribution systems S18: Provide individual controls for ventilation S19: Separate air intakes from pollution S20: Use carbon dioxide sensors to monitor ventilation rates and to provide ongoing information concerning air quality S21: With the help of building users and owner, reduce pollution sources S22: Ensure that indoor air is free of pollution	According to (WBDG, 2021): S1: Ensure a healthy interior performance through civilized environment and healthy interior environment inclusive of extended options for fresh air and controls S2: Use carbon-free renewable energy resources S3: All projects must supply 105% of project's energy needs S4: Develop and incorporate a resilience strategy S5: Consider deconstruction and appropriate durability in product specifications
Construction	Construction	Building Systems Design – Envelope Design	According to (International Living Future Institute , 2019): S1: Design an energy-efficient envelope: appropriate insulation, tight construction and high-performance, low-e windows (when this reduces life cycle costs) S2: Avoid thermal bridges in walls (use continuous insulation, or eliminate metal studs in outside walls, or otherwise ensure thermal break) S3: Optimize solar heat gain and reduce glare S4: Locate and size fenestration to capture the wind and fresh air available on site	According to (WBDG, 2021): S1: All projects must connect people with nature in both interior and exterior of the project

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Building Systems Design – Ventilation Design	According to (International Living Future Institute , 2019): S1: Set ventilation targets S2: Select an efficient mechanical or natural ventilation system S3: Assess the potential for heat recovery systems S4: Consider using zones to group areas with similar occupancies and ventilation needs S5: Weigh the benefits of VAV (variable air volume) air distribution systems S6: Provide individual controls for ventilation S7: Separate air intakes from pollution S8: Use carbon dioxide sensors to monitor ventilation rates and to provide ongoing information concerning air quality S9: With the help of building users and owner, reduce pollution sources S10: Ensure that indoor air is free of pollution	According to (WBDG, 2021): S1: Select interior materials with lower than industry average carbon footprint S2: Prohibit smoking within any buildings or enclosed spaces including air supply vents S3: Develop a healthy indoor environment plan that tackle cleaning protocols and improves air quality S4: Provide direct exhaust for kitchens, bathrooms and janitorial areas S5: Provide sufficient functioning windows that provides natural ventilation for a minimum of six months per year S6: Occupants can change their airflow and temperature through direct inputs or controls
Construction	Construction	Building Systems Design – Water System Design	According to (International Living Future Institute , 2019): S1: Install water-efficient toilet fixtures S2: Install alternative wastewater technologies S3: Select and install water-efficient fixtures S4: Install water meters to allow measurement of potable water consumption S5: Minimize energy use in water systems	According to (WBDG, 2021): S1: Capture precipitation or closed loop water systems or infiltration S2: Recycle used project water and purify without chemical use S3: No potable water use for non-potable uses S4: Address grey and black water through on-site treatment and reuse
Construction	Construction	Building Systems Design – Lighting Design	According to (International Living Future Institute , 2019): S1: Install high-efficacy lamps & fixtures S2: Maximize daylight to reduce the need for electric lighting S3: Ensure occupied spaces have direct access to outdoor views S4: Ensure all occupied spaces have access to daylight S5: Reduce glare and unwanted heat gain by using sun shading, interior or exterior window treatments and or light shelves S6: Consider consulting professionals S7: Provide individual controls for lighting where feasible S8: Minimize glare and visual discomfort from electric lighting sources	According to (WBDG, 2021): S1: Provide outside and daylight for 75% of regularly occupied spaces S2: Projects must demonstrate shading of adjacent buildings will not have a negative impact on the occupants of those buildings

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Building Systems Design – Mechanical Design	According to (International Living Future Institute , 2019): S1: Optimize mechanic al system to meet reduced loads by avoiding over-sizing equipment S2: Install high-efficiency heating and cooling equipment S3: Maximize the use of passive heating and cooling, using such methods as solar heat gain and natural ventilation S4: Explore the life-cycle costs renewable and alternate energy sources S5: Do a computer-simulated energy modelling of the building, to minimize energy use by optimizing the site, envelope, ventilation, water, lighting, and mechanical systems design S6: Reduce ozone depletion by using HVAC systems, refrigerants and fire-suppressant equipment that do not contain CFCs, HCFCs or Halons S7: All major building system designs should be documented for commissioning S8: Monitor carbon dioxide to ensure indoor air quality S9: Perform ventilation effectiveness S10: Ensure adequate air filtration	S1: Install renewable energy systems (WBDG, 2021)
Construction	Construction	Building Systems Design – Finalize Building Systems Design	According to (International Living Future Institute , 2019): S1: Finalize energy and environmental performance targets S2: Reduce internal loads by installing high-efficiency appliances S3: Provide built-in recycling amenities that make it easier for occupants to recycle than throw away S4: Provide built-in composting amenities, including storage and use areas for composting S5: Select indoor finishes that are recycled or salvaged S6: Select indoor finish materials for minimal indoor air pollutant emissions S7: Surfaces exposed to inhabited spaces, supply or return air should not trap or release dust, mineral or glass fiber S8: Locate air intakes distant from sources of outdoor pollution	S1: Install renewable energy systems (WBDG, 2021)

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Construction	Construction	Specifications / Construction Drawings	According to (International Living Future Institute , 2019): S1: Specify the overall environmental intent of the project S2: Provide detailed spec and drawing information for the preservation of site ecology S3: Provide detailed spec and drawing information for all site water features S4: Specify the package of energy conservations measures and other systems that were selected through the use of energy computer simulation software S5: Specify energy efficient equipment S6: Specify that all mechanical systems and all ventilation systems meet current best standards S7: Specify space around ventilation equipment S8: Specify products and systems that use water efficiently S9: Specify salvaged, recycled and efficient materials as much as possible S10: Specify local materials, rapidly renewable materials, minimally processed products, low-emissions products, alternatives to ozone-depleting substances, alternatives to PVC, polycarbonates, and other hazardous components, and durable and low maintenance materials and products S11: Minimize the disposal of construction waste S12: Commission all major systems S13: Conduct the final energy simulation to verify performance	According to (WBDG, 2021): S1: All projects must safeguard access for occupants with physical disabilities S2: Projects may not restrict access to the edge of any natural waterway except to those that are public safety
Construction	Construction	Construction and Commissioning	According to (International Living Future Institute , 2019): S1: Prevent erosion during construction by minimizing site disturbance S2: Ensure protection of site ecosystem by protecting rare vegetation, large trees, and watercourses are protected during construction S3: Use a formal Site Sediment and Erosion Control Plan to ensure that stormwater does not erode site soil and contaminate local water bodies S4: Construction and demolition waste is reused, recycled or salvaged for later reuse S5: Ensure that the contractor follows a formal Waste Management Plan S6: All topsoil removed during construction is saved and reused S7: Develop and implement an Indoor Air Quality Construction Plan S8: Plan and implement construction sequencing that requires absorptive materials (like insulation, carpeting, ceiling tiles, gypsum, textile materials) to be installed after drying or curing of materials that may emit chemicals S9: Ensure absorptive materials are safe from moisture damage [26] S10: Ensure supply and return air duct systems are clean and verified before occupancy S11: Conduct a complete building flush out using new filters and 100% outdoor air for a minimum of one week before occupancy S12: All major building systems are commissioned	According to (WBDG, 2021): S1: All projects must conclude a post-occupancy evaluation to address health benefits identified from it S2: All projects must avoid the use of red list chemicals

Table 5. Green Building vs. Living Building Pre-construction Strategies.

Stage	Dimension	Goal	Green Building Strategies	Living Building Strategies
Post-Construction	Operational and Maintenance	Facility Management	According to (Ibrahim, 2020): S1: Use design tools such as energy modeling and computational fluid dynamics to avoid oversized building systems that lead to both money and energy waste S2: Rely on smart building systems and devices to enable facility managers gather, analyze and act on building performance information reducing costs and energy consumptions	According to (Dittrich, 2001): S1: Train building occupants, facilities managers, and maintenance staff in sustainable design principles and methods that will minimize system failures S2: Purchase cleaning products and supplies that are resource-efficient, bio-degradable and as safe as possible for both janitorial staff and building occupants, and thereby ensure good indoor air quality S3: Test sensor control points on a regular basis to ensure energy efficiency is not compromised S4: Use automated monitors and controls for energy, water, waste, temperature, moisture, and ventilation S5: Reduce waste through source reduction, reuse, recycling and/or composting to eliminate disposal of reusable materials at landfills and incinerators S6: Minimize travel by supporting telecommuting programs and enabling a mobile work environment S7: Perform scheduled energy audits and re-commissioning of systems; and When updating a facility or its systems, choose higher efficiency equipment and durable materials that will withstand storms and other natural events, and improve the tightness of the building envelope if feasible

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Service and application under cyber physical system: information integrating and sharing for smart buildings and facilities in real-time

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Abstract

To achieve a more efficient and economical use of resources while providing a safe and comfortable environment for occupants, smart buildings are designed or retrofitted to progressively integrate future technological developments based on existing, widely used technologies. Cyber-physical systems (CPS), controlled or monitored by computer-based algorithms, can seamlessly connect digital and physical spaces to improve the adaptability, autonomy, efficiency, functionality, reliability, security, and availability of smart buildings.

In a smart building with CPS, people perform various interactivities, and in addition, multiple autonomous/non-autonomous heterogeneous facility/devices are connected to a control network, and each usage/generated data is stored in its database. The collection pattern and structure of such a database must be understood by both humans and machines for the realization of smart buildings.

We model the database of the CPS with an ontology semantic system to improve the interoperability of applications and system services. The CPS-oriented ontology designed in this study focuses on integrating information from both temporal/spatial dimensions, as well as the event processing strategies they support, and establishes an ontological framework with representative background knowledge. For data and connections with different conditions and functions, the knowledge graph built based on this ontology describes them as entities in different domains and as relationships between entities. It serves as the infrastructure for the CPS database, that the knowledge graph of the smart building then can be queried, discovered, and shared across applications. On the basis of a partial classical domain ontology, combined with the required expressions, we give formal definitions of the main concepts and properties, as well as the hierarchical relations between the cross-subject concepts. The emergency drill scenario is used to finally testify the proposed ontology.

Keywords

Digital twin, Ontology, Knowledge graph, Data integration.

1. Introduction

Recent advances in sensing, networking and intelligence technologies have led to the rapid emergence of smart buildings as a reality. Related research objectives range from low-level data acquisition by sensors to high-level contextual knowledge integration and inference. When data generated by human activities as well as smart building systems are correctly and automatically identified, a wide range of applications and services become possible, such as autonomous mobility, consumption management, security management, etc. [1]. The concept of Cyber-Physical Systems (CPS), proposed as a complex, multidisciplinary, human-computer interacting engineering system, has penetrated all aspects of the daily activities of smart buildings. It integrates the physical world into cyberspace, or a digital twin, for optimization and interpretation using computing technology, communication control, convergence of information and physical processing [2].

A desirable CPS for a smart building is assumed to have the ability to facilitate the integration of data between multiple real/virtual devices and facilities in real time by storing and unifying the data [3]. For example, it may generate and update virtual duplication in real time by using certain game engines and integrates various data that are shared among multiple services for realistic spatial control. Data utilized/generated from such system, not to mention those reproduced in the CPS, often show a lack of semantic information and topologic relationships. Furthermore, data can be incomplete, unreliable, incorrect, also one type of information can be expressed by different physical measures. To process heterogeneous data of various sources, it is important for the data processing platform to realize both the integration of information and the interoperability of applications. Ontological modeling is used to explicitly specify core concepts and their attributes within the problem domain to identify and describe entities and their relationships. These concepts are organized and diagrammed in a hierarchy to form class and subclass relationships [4]. With such a knowledge representation of the graph structure, it becomes possible for the service provider to search and retrieve the necessary information based on the graph and to use it for analysis based on the patterns of the graph [5].

In this study, we designed a CPS-oriented ontology, Spatial-temporal urban digital twin Ontology, describing entities of people, objects, data, etc. under various domains and relationships among them. It can build enough application scenarios in the virtual space to reproduce realistic smart building life, optimize data management, simulate special scenes, etc. according to actual demands. This allows our application developers to easily retrieve and analyze the information they need for service and physical/virtual space control. Moreover, as one of the use cases of a smart building CPS, the scenario of emergency drill is applied with the proposed ontology and constructed for a knowledge graph, in order to testify the practicality and applicability of the designed ontology. Here, for the key spatial information metadata obtained, we indicate the method used to transform the building structure data.

The paper is organized as follows: Section 2 introduced related work for laying the research ground and technology comparison. Section 3 details the design method of the proposed ontology. Section 4 uses an actual example to verify the proposed ontology. Finally, Section 5 summarizes the whole work.

2. Related work

2. 1 Cyber-physical system

A Cyber-Physical System (CPS) represents a higher degree of integration and coordination between physical and computational elements. It deeply interweaves physical and software components at multiple spatial and temporal scales. Sophisticated system designs can execute and interact with multiple behaviors as the environment changes [6]. As shown in Figure 1, a mature CPS typically has an interactive network of physical inputs and outputs, with a design philosophy closely related to a network of robots and sensors [7], combined with a practical, intelligent mechanism that is dominant in smart buildings.

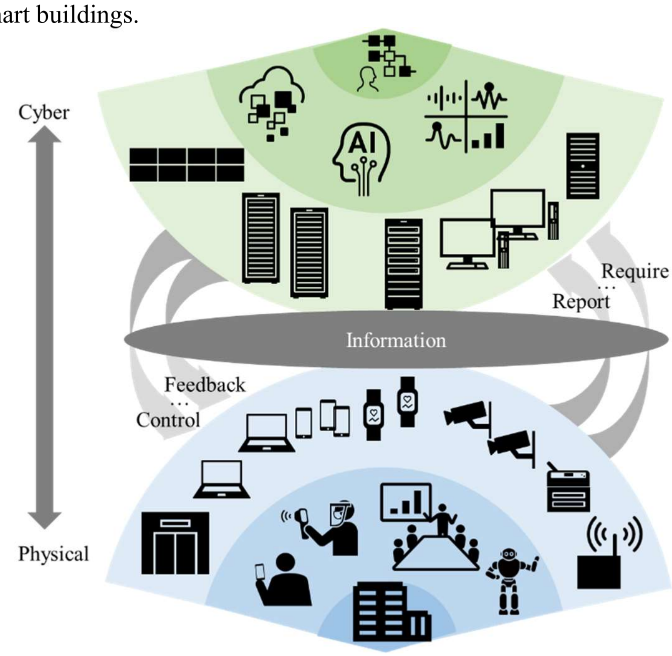

Fig. 1. Architecture of cyber-physical system

An advanced CPS is expected to share and reproduce spatial and temporal data and establish a digital twin of smart buildings, which means it can enable better decision-making and control in real-world environments through virtual rehearsal/deduction. In such context, such CPS platform should own semantic knowledge of the static environment information and various dynamic living scenes, which enables machines to recognize surroundings to collaborate under shared space and contextual awareness with humans and facilities.

2. 2 Ontological modeling

On the one hand, ontologies help to achieve a natural abstraction of the topology of the entity-relationship network that can support interoperability. On the other hand, a logical and clear hierarchical design as well as reasoning techniques can both simplify the modeling process and support the implementation of complex intelligent behaviors within smart buildings.

Regarding semantic databases applied to smart spaces, many studies have proposed various domain ontologies to simulate and model them. Some of them focus on smart systems in small spatial scopes, such as smart homes, smart offices, etc. Most of them pay attention to the interactivity between humans and their surroundings and consider the data updates generated by various activities at certain level, such as COSE (Casas Ontology for Smart Environments) Ontology, SOUPA (Standard Ontology for Ubiquitous and Pervasive Applications), etc. [8, 9]. However, due to the small scope of activity space, they involve limited scenarios, people, and objects, with long data update cycle. Some ontologies extend the spatial scope to the building level, but they focus more on the optimal integration of equipment and facilities without considering the activities and interventions for human beings, while the updates in the time dimension are also limited, such as RealEstateCore Ontology, etc. [10]. Meanwhile some domain ontologies focus aims at the extension of human activities on the time scale, with limited consideration for space, such as COBRA-ONT (COntext BRoker Architecture-ONTology) [11], etc. "Spatial-temporal urban digital twin Ontology" presented in this study takes into account the relationship between smart buildings and the activities of people in them and is accurate in the 3D spatial dimension and updated in real time in the temporal dimension. It fills a gap in the CPS field and can be used both as a base line and as a framework to provide a database model for a wide range of specific services and application scenarios together with other domain ontologies.

3. Methodology

A well-designed ontology helps realize the goal of smart building CPS by integrating heterogeneous data and allowing a common understanding shared in one building or buildings. When designing the Spatial-temporal urban digital twin Ontology, we took into account these points: first, considering the number of projects and packages, the proposed ontology enables the reuse of classic domain knowledge; second, the proposed ontology makes domain assumptions explicit so that specific use cases (e.g., emergency drills) can verify these assumptions and alter them if needed; and finally, the proposed ontology was developed with compatibility for its powerful mechanisms being able to framing other components.

3. 1 Core concept

The proposed ontology describes data in two categories: static data, including metadata of building information, people, devices and facilities, and their objects/data attributes (object attributes refer to substantial, point-to-point, relationships between entities, while data attributes, especially spatial and temporal attributes, can be assigned as variables to entities.) and relationships; dynamic data, which is responsible for carrying external inflow data, event information, etc., updates the attributes and relationships, and specific temporal/spatial data will be written into the knowledge graph as entities linking to static data directly.

For the development of functions and applications around the core concepts of CPS, spatial and temporal data are critical. Every entity present in the building should be wrapped with corresponding object attributes and data properties: for spatial positioning, first, we refer to the metadata that is properly extracted and transformed from the BIM data, waiting for be linked to any device, man or activity entity as the object attribute, then, an entity can be assigned to a point (x, y and z coordinates), a 2D (2 Dimensional) plane or a 3D (3 Dimensional) volume with specific value as the data attribute. Such a labeling method is appropriate for aggregating multi-source data into a plane or volume; for temporal positioning, first, there should be a temporal entity branch as an object attribute that allows us to dynamically describe events and activities unfolding along the timeline, and then, events and activities also have specific temporal data attributes. Both attributes should be designed with "time interval" and "time stamp" to provide different perspectives of time. Note that the convention of using timestamps needs to be specified, which means that it should be clear whether the timestamp indicates the beginning, middle or end of a discrete time interval.

The required ontology supposed to be categorized as follows:

- Agent: It is to organize information of man as well as the machinery with autonomous activities. Its functionality is twofold: first, describing objective information about an individual (e.g., name and age) and identifying his/her role (e.g., employee, customer, etc.). Both can be changed for multiple events with one individual or one event with multiple individuals, therefore this class is designed to capture and adapt this complexity.
- Factor: For smart buildings, a large number of IoT devices is inevitable, and these devices constitute an e-physical network for information interoperability and sharing. In addition to electronic devices with simple functions, such as printers, air conditioning units (whose state is, of course, crucial for energy/resource optimization), we focus more on sensors. Most of the CPS in-flow data should be streams of time-stamped values generated by heterogeneous sensors deployed in the building or attached to the agent.
- Product: It is to record the impact on the building environment caused by the results of activities and events. Even though the impacts are the result of dynamic activities or events (e.g., machine damage, facility recovery, etc.), they are written in static final result-labels or process-logs to reduce the data redundancy in the database.
- Spatial info: As discussed before, for modelling the common location knowledge in smart buildings, all building units in a smart building, such as offices, meeting rooms, activity centers, etc., can be describe as an entity to position agents, factors, events, etc.
- Event: We designed two branches: active events, which are interactions initiated by agents, i.e., activity; passive events caused by some non-human or unintentional human factors, and it also includes experience to record reactions, behaviors, etc. of agents in those events. Moreover, to establish a close association with spatial info, the relationships of event locations are described as a special branch. Each event entity is initially provided by the sensor data and recorded after data processing, which necessarily involves other dynamic/static subjects, such as spatial location, agent, time, etc.
- Data: All the data entities are provided by a variety of heterogeneous real or virtual sensors. Data collected from different sensors are completely different in data format, and the lack of a unified representation of theses data can lead to weak interoperability and reusability. This class is designed to provide a mechanism to manage perceptible data and annotate such heterogeneous data with peer-to-peer semantics, and ultimately improving interoperability and providing contextual information.
- Occurrent: As mentioned before, it consists of time interval and time stamp, in order to concretize the timeline and to establish a sound temporal space for subsequent analysis. They will be associated with events, agents, etc., therefore, the occurrent entities may be added, subtracted and changed at any time.

3. 2 Framework and conceptual modules

Having studied existing domain ontologies [12, 13], though none can completely meet all our requirements, certain relevant ontologies or design patterns can be partially reused. Therefore, the Spatial-temporal urban digital twin Ontology we proposed connects and alters a series of ontologies for describing various sub-domains required for contextual knowledge modeling, and for most of the special smart building applications, we design the corresponding classes from scratch.

The more generic an ontology is, the more likely it is to be usable, but the less likely it is to be reused in heterogeneous applications. Accordingly, we employ an upper ontology, multiple general subjects (generic, domain-independent for different knowledge domains, such as, temporal subjects, spatial subjects and agent subjects), multiple domain subjects (modeling common concepts and aspects of certain application topics), and special scenario-regenerating subjects for a smart building, and together they allow modeling both generic and specialized concepts for the proposed ontology. Protégé [14], providing a graphical user interface to model classes, properties and relationships, is used here for the construction of proposed ontology and specific knowledge graph.

skos (Simple Knowledge Organization System)(https://www.w3.org/TR/2008/WD-skos-reference-20080829/skos.html) was chosen as the upper-level ontology due to its wide reusability and comprehensive base. It provides a set of architectural concepts to facilitate interoperability and align with many mid-level and lower-level subjects.

For general subjects, namely temporal, spatial, and agent ontologies (to describe who, where, when), respectively, we used FOAF (Friend Of A Friend)(http://xmlns.com/foaf/0.1/) ontology to model generic information about an agent, such as the name, age and profile, and to provide the description of agent relationships. Time (https://www.w3.org/TR/owl-time/) ontology is to describe the temporal properties in the real or virtual world. The ontology provides a vocabulary for expressing topological relations among time instants and intervals, together with information about durations and temporal position. BOT (Building Topology Ontology)(https://w3c-lbd-cg.github.io/bot/), as spatial ontology, is introduced as a minimal, classic ontology for describing the core topological concepts of a building. It can be an extensible baseline for keeping the schema no more complex than necessary.

As for domain ontologies, in most cases they generate subordinate or executive relationships with certain topics, hence the chosen ontology theories that, in addition to containing sufficient branches, should also have a large number of object attributes to describe the exhaustive connections. Therefore, to express building elements (e.g., walls, doors, etc.), ifcowl (a Web Ontology Language representation of the Industry Foundation Classes)(https://standards.buildingsmart.org/IFC/DEV/IFC4/ADD2_TC1/OWL/index.html) ontology is adopted for entities being directly obtained from BIM (Building Information Modeling) data conversion, while to describe various devices (e.g., AC, vending machine, etc.), generic SSN (Semantic Sensor Network)(https://www.w3.org/TR/vocab-ssn/) ontology is utilized. The Event Ontology (EO: https://motools.sourceforge.net/event/event.html) is used to identify events in the building. Although activity is a subclass of events, after investigation, dicp (Processes of Digital Construction)(https://w3id.org/digitalconstruction/Processes) ontology complements EO in detail, and human activities are one of our focuses, so we additionally introduce dicp. Naturally, we do not express all sub-subjects with existing ontologies, since some entities are strongly related to the CGPF special applications and none of the existing ontologies is adequate, which pushes us to independently design this part.

For the CPS application subjects of a smart building, we have newly designed various branches/sub-branches, and their related object attributes and data attributes according to the scenario to be described. Since the architecture of required Spatial-temporal urban digital twin Ontology and the core concepts in it have been defined, this means that a structured and formalized knowledge base has been created. On this basis, specific subjects and actual use-cases can be developed and designed to improve efficiency and practicality. Most of them belong to broad branches, while specific design methods include completely new design sub-branches, expanding sub-branches of an ontology, rewriting sub-branches of an ontology, and fusing several ontologies.

Figure 2 gives a picture of the various classes of the Spatial-temporal urban digital twin Ontology and the connections between them.

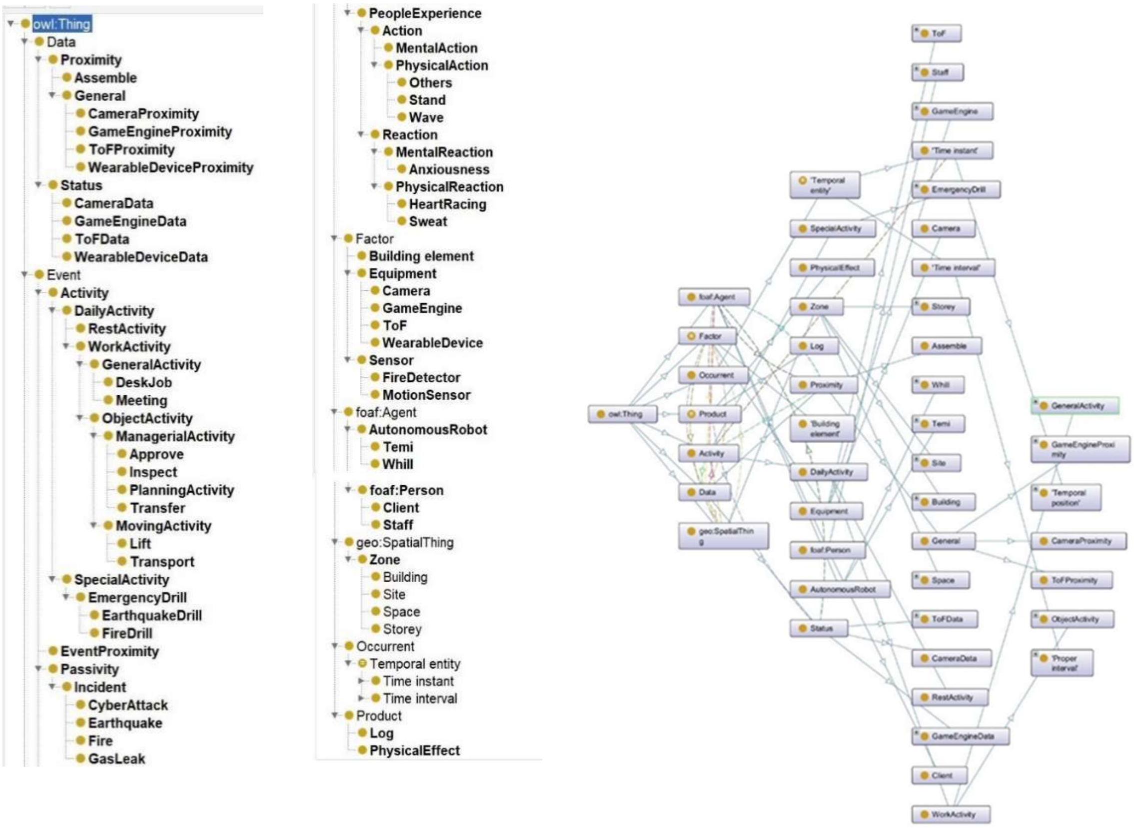

Fig. 2. Snapshot of Spatial-temporal urban digital twin Ontology

4. Verification and discussion

To verify the feasibility and completeness of the proposed ontology, we examine its data management and integration performance under a specific scenario in smart buildings.

4. 1 Metadata conversion of building structure

Firstly, the structural data of the smart building is required for spatial information. BIM is a computer-generated representation of the actual components used in a building. IFC (Industry Foundation Classes) holds information about each of these components and facilitates the exchange of data between software. Modern buildings, including smart buildings, improve operational efficiency by distributing attribute information data in IFCs to exchange three-dimensional data about buildings and civil structures.

In the validation study, we instead assume that building information is stored in the form of IFC files, from which we extract building entities (e.g., doors, walls, rooms, etc.), entity attributes (e.g., door dimensions, wall materials, etc.), and relationships between entities (e.g., doors on a particular wall, rooms on a particular floor, etc.). One way is to use the official RDF parser to convert IFC files to the knowledge graph on the ifcOWL ontology framework [15]. However, for our proposed ontological framework, such detailed metadata would instead create data redundancy. This is because our focus is on the constant inflow of dynamic human activities, real-time state information, etc. Although static spatial data is the basis of the whole knowledge graph, the large amount of material information and supplier information recorded in the IFC file cannot be utilized in the Spatial-temporal urban digital twin Ontology, and we need to eliminate them to save storage space, computing power, and streamline the data framework. Therefore, the BOT ontology, which is also the minimal ontology describing the core building topology concepts, is used in the "SpatialThing" class of the Spatial-temporal urban digital twin Ontology. However, we keep some of the ontologies described by the ifcOWL ontology in the "building element" subclass. Figure 3 shows the data conversion pipeline from IFC file to final BOT ontology-based RDF (Resource Description Framework) database. We used the mentioned official IFCtoLBD converter to obtain ifcOWL based RDF data which is then aligned to BOT ontology RDF data while saving key ifcOWL RDF data.

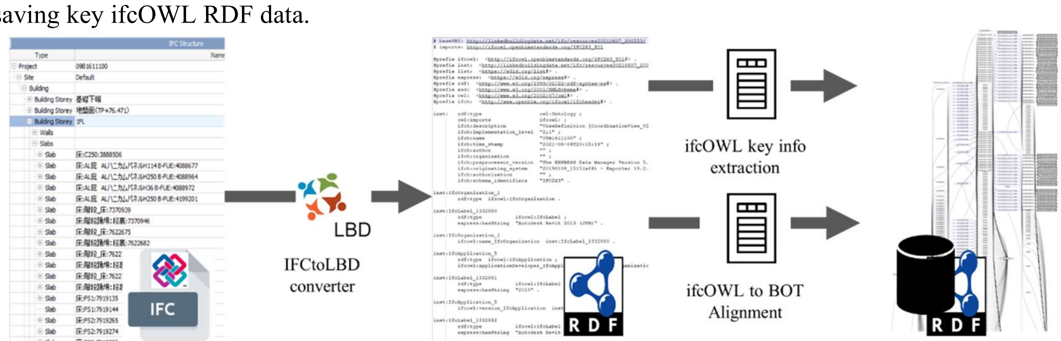

Fig. 3. Conversion pipeline

4. 2 Establish of knowledge graph

The validation study must contain a sufficient variety and number of entities and their relationships, for which we choose "emergency drill" scenario. In the proposed ontology, under “specialactivity” class, “emergencydrill” subbranches have been designed to represent the hierarchy of related events and have been established with the required object attributes to associate with other classes or subclasses.

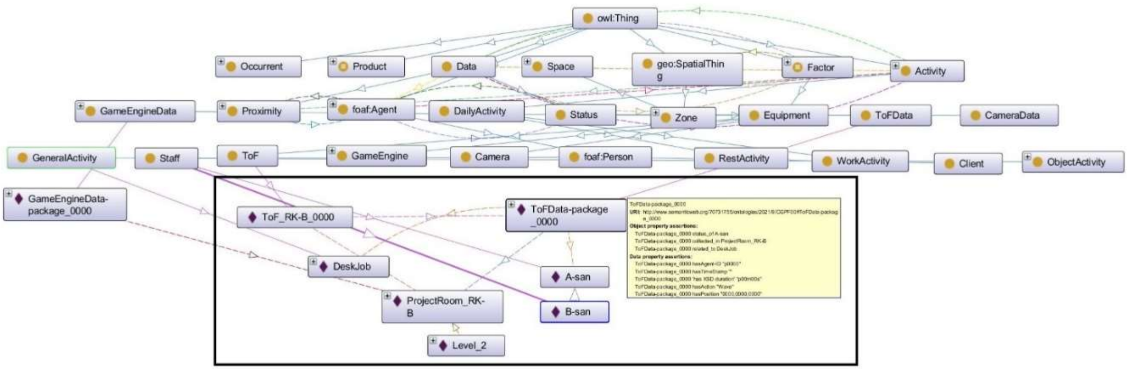

Fig. 4. Representation among entities and attributes in fire drill scenario

Since the activity will involve the collaboration of people and objects within the building, entities of this subbranch will have connections to each participating other subject entities to reflect their roles in this scenario. Specifically, in the case of the fire drill: firstly, we assume that a certain number of employees are proceeding with their daily work activities, and these event entities will be recorded in an "activity" subbranch parallel to "passivity". Naturally, in addition to the broad level recording, details of their actions/reactions behaved in the activities are also recorded in "PeopleExperience". They are captured by various sensors, such as cameras, wearable sensors, etc. The heterogeneous data are processed and fed into the corresponding "data" classes or data attributes, where the most critical procedure is to build and update the association of object attributes with temporal and spatial entities; then the fire occurs, the real and data environment of the entire building produces changes in the state of people and objects, and ontological entities change. The notification of the fire is captured and transmitted from the cameras/fire-alarm sensors and established its own temporal and spatial object/data attributes as general rules of "event". At the same time these entities (fire, time, space, etc.) are going to associate with agents, devices, etc., causing a change in their position, status/activity, psychophysiological changes (such as increased heart rate, sweating, etc.), etc. As the fire progressed, new entities (such as people escaping, firefighters entering, etc.), renewed entities (status data, position, etc.), deleted entities (daily activity, action, etc.), all these recording will be updated repeatedly with the data sampling frequency. The specific representation between entities and attributes is shown in Figure 4.

We assume that all data are in-flowed externally, which will certainly create problems such as inconsistent formatting, data redundancy, etc. Therefore, in our ontological theory, some core data is processed at certain level before written/rewritten into the knowledge graph, whose form of related temporal and spatial data is specified for the purpose of data streamlining.

5. Conclusions

To achieve optimal strategy and control of smart buildings, CPS can help share large amounts of heterogeneous data to connect people, objects, events, and even real space and virtual duplicand. Its integrated database should create semantic static and dynamic digital twins in time and space dimensions.

This study details the design of the Spatial-temporal urban digital twin Ontology, which is the cornerstone of data sharing, management, and integration in-question. A special schema is proposed for representing contextual knowledge and complex-event processing while supporting temporal/spatial reasoning. We construct a suitable overall framework, then find suitable existing ontologies and localize them as upper, general and domain ontologies, finally develop a series of Spatial-temporal urban digital twin Ontology specific application branches/subbranches. The entire design pattern including the core concepts of the main classes, the fusion framework and the conceptual modules are carefully introduced, as well as the showcase of the finalized ontology. The usability and reliability of the proposed ontology are confirmed by implementing data management/integration in an emergency drill scenario of a smart building. By capturing participants' behavioral data and storing it in a knowledge graph, the prototype is superimposed on the real space, and is verified its efficiency.

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Profitable Development of Floodplain Plagued Parcels

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Abstract

The objective of this study was to promote development of residential tracts of land that include areas subject to flood hazards as identified by the Federal Emergency Management Agency (FEMA). The concept is that re-zoning of flood prone properties using Open Space Community (OSC) criteria will result in greater lot yields than could be obtained by developing the project under existing zoning classification. The authors collected historical data on re-zonings to make the case for promoting development of properties that contain floodplains. Recent re-zoning cases in Metro-Atlanta are examined to achieve the stated objective. In addition, this type of re-zoning will reduce the number of lots created that contain identified FEMA floodplain. This eliminates the need for future homeowners to purchase high-cost federally mandated flood insurance when financing their purchase using federally protected bank loans. Developers would be able to market these properties more readily to future residents since flood insurance would not be required. The intended audience were developers interested in profitable residential developments that contain large areas of restrictive acreage such as floodplains, stream buffers and steep slopes. The results of four case studies show an average increase in lot yield of 27.8% when these properties were re-zoned as open space community (OSC) projects.

Keywords

Floodplain development, OSC re-zoning, residential development, subdivision design, and natural buffers

1. Introduction

The study was undertaken to enhance the profitability of development of residential parcels in Flood Plans. The re-zoning process was found to reduce the potential of flooding in the areas where residential development takes place. In addition, the dwellers will be spared from paying high costs for flood insurance. The developers would be able to market these properties more easily to prospective residents due to lower insurance costs. Residential developers typically select tracts of land for potential projects based on the expected lot yield. The lot yield is determined by identifying the current zoning district of the tract to be developed. A developable lot is termed a "unit". The current zoning indicates the typical lot yield per acre (commonly called units per acre - UPA) that the developer can expect to obtain from the parcel of land. To determine the lot yield of a parcel, take the parcel area (in acres) and multiply by the UPA number specified in the zoning of the property, [example: a tract of land located in an R-20 zoning district would have an expected lot yield of 1.75 UPA. If the parcel of land were 40 acres, then the developer could expect to obtain 70 buildable units: (40 acres) (1.75 units per acre) = 70 buildable units.

If the parcel of land has floodplain located within, the total buildable area can be dramatically reduced due to governmental regulations restricting the building of residential dwellings to areas that are located outside the identified 100-year flood hazard area.

Open Space Community (OSC) Zoning

OSC overlay re-zoning is a way for developers to minimize the adverse aspects of developments that have large areas of non-buildable area. OSC re-zoning is dependent upon separating a minimum of 35 percent of the original tract from the total area of the parent tract. County code dictates open space should be comprised of 100-year floodplains, stream buffers, wetlands, archeological sites and cemeteries or burial grounds. The remainder of the tract is used to construct buildable lots and roads for the development. The new lots are substantially smaller in square footage than the minimum lot size requirement per existing zoning. As an example, for OSC overlay re-zoning from existing R-30 to R-20/OSC, the lot size for the original R-30 zoning would have required minimum lot sizes of 30,000 square feet. Normal R-20 zoning requires a minimum lot size of 20,000 square feet. R-20/OSC re-zoned tracts require a minimum lot size of 13,000 square feet.

This represents a 57% reduction in lot size over the original R-30 zoning requirement and a 35% reduction in lot size for the normal minimum R-20 zoning lot size.

Table 1. Density and Open Space Requirements for Standard Residential Zones (Cobb County GA, 2017)

District Designation	**Min. Lot Area**	**(UPA)Units per Acre**
R-30	30,000 ft²	1.1 avg.
R-30/OSC	**15,000 ft²**	**1.1 avg.**
R-20	20,000 ft²	1.75 avg.
R-20/OSC	**13,000 ft²**	**1.75 avg.**
R-15	15,000 ft²	2.1 avg.
R-15/OSC	**10,000 ft²**	**2.1 avg.**

The first column in Table 1 lists the zoning category. The second column shows the minimum lot size requirement for the zoning category. The third column lists the expected lot yield per acre based on the minimum lot size requirement.

When re-zoning a parcel to overlay Open Space Community (OSC) zoning, the developer is expected to separate the 100-year floodplain from the parent tract. Floodplain can only make-up 70% of the area set aside for open space. Other non-desirable areas (buffer zones, wetlands, streams, etc.) can be grouped with the floodplain to form one or more undisturbed tracts. Together these separated parcels need to add up to a minimum of 35% of the original tract being developed to qualify as an OSC re-zoning. If not, additional square footage will need to be added until the separated parcel(s) equal the 35% minimum required. The remaining parcel of land is subdivided into much smaller lots than those required by the original zoning of the parcel. The resulting subdivision provides the developer with an overall greater lot yield than would have resulted based on developing the same property under the original zoning category.

In addition, none of the lots created contain identified 100-year floodplain.

Landowners and developers could be compensated for preserving open land. For instance, developers could be granted permission to increase the density of their developments through so-called density bonus credits (Sheaffer, 2002).

Floodplain Definition

In 1968, Congress established the National Flood Insurance Program (NFIP) with the passage of the National Flood Insurance Act. This Act was an effort by the government to make flood insurance affordable and available to assist the public in recovering from flood damage. In exchange for this offer, State and community floodplain management regulations were enacted to reduce future flood damages by enforcing new building developments to areas outside the identified 100-year or "Base Flood" hazard area as identified by the Federal Emergency Management Agency, (FEMA).

The 100-year flood hazard area is technically defined as the 1-percent-annual-chance flood. The 1-percent-annual-chance flood was chosen on the basis that it provides a higher level of protection while not imposing overly stringent requirements or the burden of excessive costs on property owners. The 1-percent-annual-chance flood (or 100-year flood) represents a magnitude and frequency that has a statistical probability of being equaled or exceeded in any given year, or stated alternatively, the 100-year flood has a 26 percent (or 1 in 4) chance of occurring over the life of a 30-year mortgage. (FEMA, 2002, p. 5).

Although FEMA provides communities with guidance on open space development, specific open space land uses are at the discretion of the local community. Local governments are encouraged by FEMA to develop the acquired properties in a manner that is "compatible with open space, recreational, or wetlands management practices, and consistent with conservation of natural floodplain functions" (FEMA, 2009, p. 39).

Cost of Flood Insurance

The cost for flood insurance varies based upon several factors such as the year the home was built, occupancy of the home, number of floors (including basement), location of personal belongings in the home, deductible of flood policy and most importantly the actual flood risk of the property. The three basic categories of flood risk properties are low, moderate, and high risk.

The most favorable designations are "moderate and low risk". These properties have a lower average cost of flood insurance because the coverage is not required as it is not likely that a flood will occur. These areas are designated as Non-Special Flood Hazard Areas or NSFA by FEMA. The probability of flooding is 0.2 to 1 percent for moderate-risk and less than or equal to 0.2% for low-risk designated properties.

Properties located in known flood zones as identified by FEMA are "high-risk areas". These areas are designated as Special Flood Hazard Areas or SFHA. There is a greater than 1% chance of flooding each year.

For a $250,000, one-story house with a basement located in a "moderate or low risk" area, the yearly flood insurance cost would be $427 per year with a $5000 deductible. This includes $100,000 coverage for replacement of personal items located within the dwelling.

For the same dwelling, but located in a "high-risk area", a yearly premium of $2482 could be expected for the same amount of coverage.

2. Data Collection

This explanatory case study is a mixed-method approach comprised of OSC re-zoning cases and semi-structured interviews of major stakeholders in the development of floodplain prone properties.

Initially 87 re-zoning cases comprised the study sample. These cases represent the re-zoning petitions reviewed by the Planning Commission in Cobb County, GA during 2017. While reviewing these cases it was decided to focus on those re-zoning cases involving OSC overlay criteria. OSC re-zoning criteria specifically states that floodplain prone areas of the parent tract are to be used as part of the open space area. OSC cases are reviewed to establish any connection between OSC re-zoning, floodplain and expected lot yields.

In 2017, there were four OSC re-zonings cases. These cases form the basis of this pilot study.

In addition to the 2017 OSC re-zoning case reviews, two semi-structured interviews were conducted with major stakeholders involved in the development of floodplain prone tracts of land. These semi-structured sessions provided opportunities to gather data using spontaneous follow-up questions as the interview proceeded. Transcripts were selectively mined for quotations that add information or clarify issues relative to the study data.

The first interview was conducted with a General Contractor who had developed properties in this county over the past forty years and is still actively doing so. This developer currently has a property undergoing review that is listed as an OSC re-zoning. His case falls under the 2018 county calendar and is not part of this study.

The second interview was conducted with a member of the Cobb County planning division who is specifically designated to review OSC re-zoning cases.

3. Results

Data analysis is based on enhancing the ability of a developer to market the rezoned lots with lower flood insurance rates. The results obtained from analysis were based on the number of additional lots generated through rezoning with the lower insurance rates.

4. Discussion

Detailed interviews were conducted with a General Contractor who has built subdivisions in the area for the past forty years. A second interview was conducted with a member of the Cobb County planning division designated to review Open Space Community Re-zoning projects. In addition, eighty-seven re-zoning cases were examined and reviewed to establish the connection between re-zoning and the increase in lot yield for floodplain developments. These cases involved all re-zoning cases submitted in Cobb County, Georgia for the 2017 year.

Through the interview process, the county official stated, "OSC re-zoning was not intended to result in greater lot yields for developers. The intent of the county was for the preservation of drainage basins and groundwater quality", (Westbrook, 2018).

A question posed to the general contractor (GC) asked how many additional lots were required of an OSC re-zoning to make it more profitable. He stated, "The addition of one lot can potentially increase profit by as much as fifteen percent", (Konigsmark, 2018).

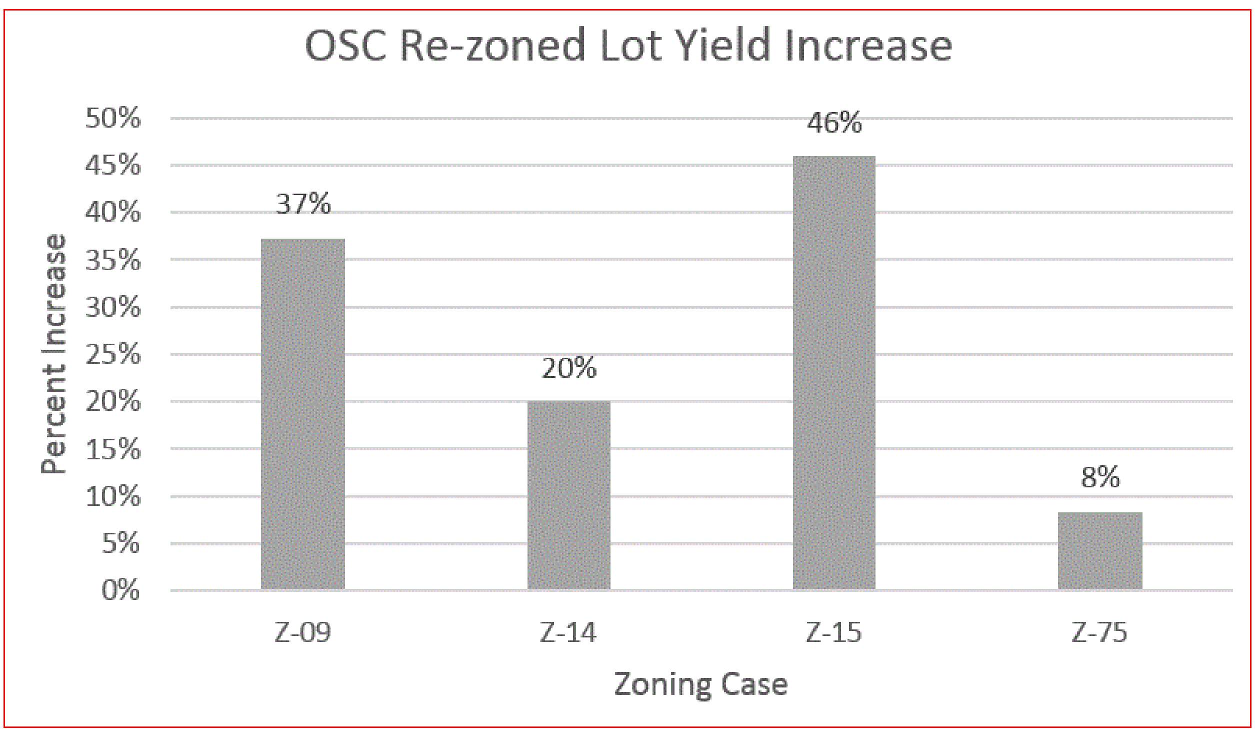

Figure 1. OSC Re-zoned Lot Yield Increase (generated by author)

In this bar chart, the vertical axis reflects the percentage of increase in lots over the original zoned lot yield. The horizontal axis indicated the four studied rezoning cases. The labels on the top of each bar indicate the percent of increase per re-zoned case.

Presented next are characteristics of the OSC cases reviewed.

Re-Zoning Case Z-9

This tract of land contains 46.962 acres currently zoned R-30. The required open space is 16.44 acres. The existing identified 100-year floodplain is 0.944 acres. A significant portion of the property set aside for open space consists of required stream buffers.

Under current zoning, the developer would realize a yield of 51 lots. To obtain this number, take the total number of acres and multiply by the expected UPA for the existing zoning category.

Existing Lot Yield Calculation:
(46.962 aces) X (1.1 UPA) = 51.66 lots (rounds down to 51 lots)
The same property re-zoned to R-20/OSC could yield 82 lots.

OSC Lot Yield Calculation:
(46.962 aces) X (1.75 UPA) = 82.18 lots (rounds down to 82 lots)

The developer finalized this re-zoning request with a proposed OSC yield of 70 lots. This results in a gain of 19 lots, or a 37% increase over current zoning expectations. Using information on the re-zoning request, the average proposed lot size is 13,369 ft². Two lots (representing 3% of the total) are substantially larger than the average. One is 49,484 ft² and the second is 95,832 ft².

Re-Zoning Case Z-14

This parcel is a 23.06-acre tract re-zoned from R-20 to R-15/OSC. Open space is 9.93 acres, which represents 43.1% of the total tract of land. None of the open space areas are in an identified 100-year floodplain. A small portion of the open space area consists of required stream buffers.
Under current zoning, the developer would realize a yield of 40 lots.

Under OSC re-zoning the same tract would yield 48 lots. This is a 20% increase in marketable lots. The average proposed lot size is 8,823 ft². The review board recommended that all lots meet the R-15/OSC required minimum of 10,000 ft² before approval. There are 35 lots smaller than required. The required area needed to increase them to the minimum of 10,000 ft² is 56,473 ft². Designated open space currently exceeds requirements by 80,978 ft². This is attainable permitting the development to meet OSC requirements.

Re-Zoning Case Z-15

A 34.2-acre tract of land being re-zoned from R-30 to R-20/OSC. Open space is 12.03 acres representing 35.2% of the total area. None of the open space areas are in an identified 100-year floodplain. Most of the open space area is comprised of required stream buffers.

Under current zoning, the developer would realize a yield of 37 lots.

Under OSC re-zoning the same tract could yield 59 lots. The developer chose to have some lots larger than the minimum required 13,000 square feet per the R-20/OSC designation resulting in a lot yield of 54 lots. This is a 46% increase in marketable lots.

Information on average lot size is not available from data reviewed for this case.

Re-Zoning Case Z-75

The last case is a 77.03-acre site re-zoned from R-30 to R-20/OSC. Open space is 31.8 acres, which is 41.3% of the total area. The existing identified 100-year floodplain on this site is 2.1 acres. Most of the open space area is comprised of steep slopes.

Under current zoning, the developer would realize a yield of 84 lots.

After OSC re-zoning, the yield could have been increased to 134 lots. The developer opted for some lots to be larger than the minimum of 13,000 ft² required and finalized the planned development to yield 91 lots. This is an 8% gain in buildable lots.

Information on average lot size is not available from data reviewed for this case.

During the interview with the GC, reasons given for a developer opting to settle for less than the maximum obtainable lot yield can be attributed to complaints from local landowners about the "increase in traffic and the overburdening of local schools" that are created by the new development (Konigsmark, 2018).

Lot Size and Valuation

In comparing lot sizes, those in Z-09 had a standard deviation of 1,769 ft² representing a 13.6% variation from the required 13,000 ft² for R-20/OSC.

When large variations in lot sizes occur, the cost per lot can significantly increase. The two acreage tracts in Z-09 would sell at a much greater price than the minimum size lots.

For Z-14, the standard deviation was 1,446 ft² representing a variation of 14.5% from the required 10,000 ft² for R-15/OSC re-zoning.

Except for the two acreage lots in Z-09, the vast majority of created lots are representative of the minimum lot size as required per each re-zoning category. The cost per lot is held constant throughout the development.

5. Conclusions

The objective of this study was to promote development of residential tracts of land that include areas subject to flood hazards as identified by the Federal Emergency Management Agency. Re-zoning of flood prone properties as discussed in the Section Discussion of Results translated to greater lot yields as compared to developing such projects under current zoning regulations. Historical data on re-zonings was used to investigate and justify the findings in this paper to promote more profitable development in flood plains.

The results of these four cases show that through OSC re-zoning these developments saw an average increase in lot yield per of 27.8%. Basing profitability solely on buildable lots created per development, more lots would equal greater profits for developers in these instances.

In addition to providing the developer with greater lot yields, OSC re-zoned tracts of land preserve in perpetuity environmentally sensitive lands in their natural condition. These saved areas result in large natural buffers to adjoining tracts of land. The initial hypothesis that areas being set aside as open space mainly would be comprised of identified 100-year floodplain (up to 70%) turns out not to be the case.

Through this exploratory pilot study, it was observed that most of the open space property consists of stream buffers and steep slopes.

Lots created through OSC re-zoning do eliminate the creation of floodplain affected residential home sites resulting in savings for future homeowners who don't have to purchase costly flood insurance as a condition of federally insured bank loans.

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Key Barriers to the Adoption of 3D Printing Innovation in Construction: A Review of Empirical Studies

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Abstract

The need to implement sustainability in construction has given birth to 3D printing innovation. It is also a potential construction technique by which the construction industry contributes to sustainable development. 3D printing has recently gained more interest in construction, thereby promising automation of building processes with its advantages in faster production, cost reduction, material minimization, and greater environmental soundness. However, numerous barriers have limited the adoption of 3D printing in construction in various parts of the world. Little consideration has been given to assessing empirical studies of current knowledge of barriers to 3D printing adoption. This paper provides a comprehensive literature review on the key barriers to 3D printing in construction. In this study, the Preferred Reported Item for Systematic Review and Meta-Analyses (PRISMA) guideline was adopted to report the systematic review of the relevant past empirical studies on the barriers hindering the implementation of 3D printing in the construction industry. A total of 36 barriers were identified during the review and classified into six (6) categories. Thirteen key barriers hindering 3D printing implementation in the construction industry were identified and discussed. This study contributed to the knowledge of the barriers hindering the adoption of 3D printing. It will enable the built environment professionals to make the right choice when it comes to how 3D printing can improve the sustainable delivery of buildings.

Keywords

3D printing, Additive manufacturing (AM), Adoption, Construction Innovation, Construction industry.

1. Introduction

The construction industry is one of the largest industries in the world and has undergone significant advancements in recent decades, including the exploration of 3D printing. This modern technology, also known as additive manufacturing (AM) (Samuel et al., 2013; Tay et al., 2017), has the potential to improve current construction techniques, and its adoption is gaining momentum in the industry. 3D printing, as described by (Kazemian et al., 2017; Ngo et al., 2018; Pacillo et al., 2021; Tay et al., 2017; Xia et al., 2019), is an advanced layered material joining technique that allows producing complex and diverse structures based on 3D computer-aided-design (CAD) models without the need for tooling, dies, or fixtures. This modern technology can convert a computer design model into a tangible object. However, despite recent advancements in automated 3D printing systems, it is evident that some barriers hinder 3D printing's wider acceptance in the construction industry. For example, the size of the printer, building site obstructions, logistical burden of 3D-printed construction, and lack of codes and standards regulations in the green building (GB) movement, as highlighted by (Guamán-Rivera et al., 2022; Guamán Rivera et al., 2021; Jagoda et al., 2020; Tahmasebinia et al., 2018).

Much research on 3D printing innovations has been undertaken over the last few decades to comprehend the recent developments, future possibilities, and problems of large-scale use of 3D printing in building projects. Due to its potential for automation, formwork elimination, construction waste reduction, and geometrical precision improvement, 3DP has much promise for applications in the construction sector. To be compatible with the technology, materials used in 3D printing must fulfil specific requirements. According to (Camacho et al., 2018), cementitious materials, metallic materials, and polymer materials are the most often used materials in 3D printing. The current research on 3D printing focuses on other materials like cementitious materials (Huang et al., 2013; Paul et al., 2018; Soltan & Li, 2018), polymer materials (Ju et al., 2017; Panda et al., 2017; Yao et al., 2019) and metal materials (Buchanan & Gardner, 2019; DebRoy et al., 2018; Frazier, 2014). The 3D printing process involves the input process of fresh materials into the 3D printing machine and the output process of a 3D-printed object. 3D-printed structures can be produced either on-site or offsite. On-site 3D printing necessitates transporting the 3D printing machine, which can be challenging and expensive (Maskuriy et al., 2019). Offsite manufacturing is also known as prefabrication. The components are 3D-printed in a factory and then moved and installed on-site in prefabrication. This was the situation with Dubai's 3D-printed workplace. The properties of 3D printing include printability, pumpability/workability, extrudability, buildability, open time, shape retention factor, and scalability.

This paper identifies and addresses the key barriers to adopting 3D printing in construction. To achieve this, a systematic literature review was conducted to answer the following questions:

(I) What are the identified barriers to 3D printing adoption?
(II) What are the key barriers to 3D printing in construction?
(III) What are the recommendations for addressing the top barriers affecting 3D printing in construction?

Through this review, the authors aim to fill the research gap by collecting empirical studies on the barriers to 3D printing adoption, identifying and classifying the most significant barriers using a qualitative approach, and providing recommendations to address them. The paper begins with a brief introduction to 3D printing in construction, followed by a description of the methodology used in this research. Next, the barriers to adopting 3D printing in construction were reviewed, and their findings, recommendations, and conclusion were discussed.

2. Methodology

This study adopted Preferred Reported Item for Systematic Review and Meta-Analyses (PRISMA) guideline as seen in Fig. 1, to report the systematic review process. The description of the process involves the following;

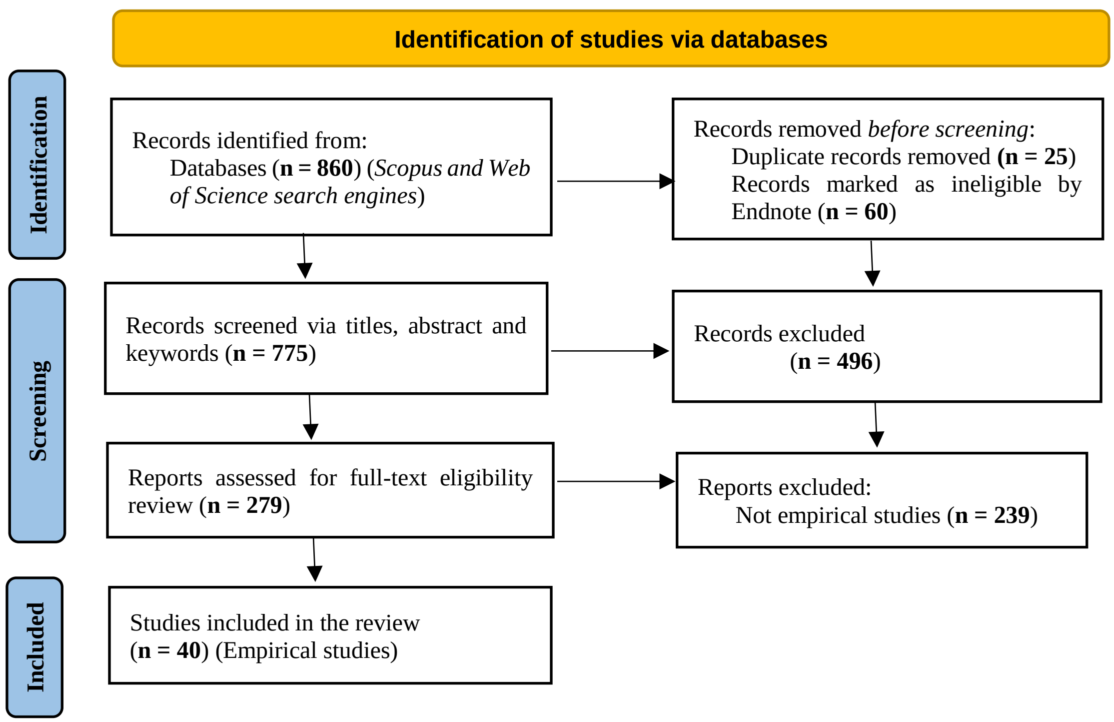

Fig. 1. PRISMA flowchart for the study selection procedure

The systematic literature review is focused on relevant past empirical studies on the barriers hindering the implementation of 3D printing in the construction industry. This review is exclusively based on relevant papers published in academic journals. A systematic literature search was based on two multidisciplinary databases of scientific research, Scopus, and Web of Science search engines. The following suited search keywords were used: "3D printing in construction" OR "additive manufacturing", AND "barriers". The initial search results of the combination of both databases cover 860 documents (Scopus: 617, WoS: 243). Then the search was limited to; “years = 2011-2022”, “document type = Research articles”, “subject areas = Engineering”, and “source type = Journal" to get current and relevant journals which resulted in about 279 papers. After filtering, 40 papers with empirical studies were found valid for further analysis. This research refers to published articles based on qualitative or quantitative data acquired from the industry using methods such as questionnaire surveys, interviews, and case studies, including experimentation when discussing empirical arguments concerning the barriers of 3D printing.

3. Results

3.1 Identification of 3D Printing barriers in construction

The first objective of this study was to identify the barriers to 3D printing in general. This objective was achieved by reviewing 40 academic publications that report empirical studies on 3D printing barriers. A total of 36 barriers were identified from reviewing several selected empirical studies. ***Table 1*** lists all the identified barriers from the selected papers reviewed.

3.2 Classification of 3D Printing barriers in construction

As shown in ***Table 1***, several barriers influencing 3D printing adoption have been identified through a systematic review of past empirical studies. To better understand the barriers to 3D printing, it is essential to classify them. The review suggests that 3D printing barriers can generally be grouped into six main categories: 3D printing process and material-related barriers, 3D printer and setup-related barriers, Design and characteristics of 3D-printed objects-related barriers, Construction and site management-related barriers, Environmental-related barriers, Regulatory and stakeholder-related barriers.

Table 1. Identification and classification of the barriers to 3DP in construction.

Group	Coding	Barriers	Reference
1		**3D printing process and material-related barriers**	
	B1	Printability	(El-Sayegh et al., 2020; Guamán-Rivera et al., 2022; Hossain et al., 2020)
	B2	Pumpability/workability	(Avinash et al., 2020; Guamán-Rivera et al., 2022; Hossain et al., 2020)
	B3	Extrudability	(Avinash et al., 2020; Guamán-Rivera et al., 2022; Hossain et al., 2020)
	B4	Buildability	(Avinash et al., 2020; El-Sayegh et al., 2020; Guamán-Rivera et al., 2022)
	B5	Shape retention factor	(Guamán-Rivera et al., 2022)
	B6	Open time	(El-Sayegh et al., 2020; Guamán-Rivera et al., 2022)
	B7	Scalability	(Sepasgozar et al., 2020; Tahmasebinia et al., 2018)
2		**3D Printer and Setup Related Barriers**	
	B8	Size of the printing system	(Guamán-Rivera et al., 2022; Tahmasebinia et al., 2018)
	B9	Size rate of the 3DP to the building object	(Tahmasebinia et al., 2018)
	B10	Suitability of the digital model for printing	(El-Sayegh et al., 2020)
	B11	Programming the machine in an efficient way	(El-Sayegh et al., 2020; Sepasgozar et al., 2020)
	B12	Positioning the printer platforms	(El-Sayegh et al., 2020; Guamán Rivera et al., 2021)
	B13	Motion programming (no effective pause and resume functions)	(Sepasgozar et al., 2020)
3		**Design and characteristics of 3D-printed objects related barriers**	
	B14	Layer-by-layer appearance	(Nerella et al., 2019; Ngo et al., 2018; Ning et al., 2021; Tay et al., 2017)
	B15	Void formation	(Hossain et al., 2020; Nerella et al., 2019; Ngo et al., 2018; Sepasgozar et al., 2020)
	B16	Anisotropic microstructure and mechanical properties	(Ngo et al., 2018)
	B17	Divergent from design to execution	(Ngo et al., 2018)
	B18	Structural integrity	(Avinash et al., 2020; El-Sayegh et al., 2020; Hossain et al., 2020; Tahmasebinia et al., 2018)
	B19	Reinforcement issues	(Hossain et al., 2020; Sepasgozar et al., 2020; Tahmasebinia et al., 2018; Vantyghem et al., 2020)

Group	Coding	Barriers	Reference
	B20	Exclusion of building services	(El-Sayegh et al., 2020)
4		**Construction and site management-related barriers**	
	B21	Cost estimation	(Bosch-Sijtsema et al., 2021; El-Sayegh et al., 2020)
	B22	Construction site setup	(El-Sayegh et al., 2020)
	B23	Obstacles to the construction site	(Guamán Rivera et al., 2021)
	B24	The logistical burden of 3D-printed construction	(Jagoda et al., 2020)
	B25	Full-size of structure	(Guamán-Rivera et al., 2022; Hossain et al., 2020; Sepasgozar et al., 2020)
5		**Environmental-related barriers**	
	B26	Insufficient demand for mass customization in construction	(Ning et al., 2021)
	B27	Insufficient environmental impact	(García-Alvarado et al., 2020; Ning et al., 2021)
	B28	Adverse environmental impact: discharge of harmful substances or emission	(Ning et al., 2021)
	B29	More susceptible to changes in environmental conditions	(Jagoda et al., 2020)
6		**Regulatory and stakeholder-related barriers**	
	B30	Lack of codes and standards regulations	(Bosch-Sijtsema et al., 2021; El-Sayegh et al., 2020; Jagoda et al., 2020)
	B31	Insufficient intellectual property protection	(Ning et al., 2021)
	B32	Lack of competence	(Bosch-Sijtsema et al., 2021)
	B33	Requirement of skilled workers	(Bosch-Sijtsema et al., 2021; El-Sayegh et al., 2020; García-Alvarado et al., 2020; Hossain et al., 2020; Tay et al., 2017)
	B34	Reduced sustainable employment	(El-Sayegh et al., 2020; Jagoda et al., 2020; Ning et al., 2021)
	B35	Scepticism about the potential of 3D printing	(Bosch-Sijtsema et al., 2021; El-Sayegh et al., 2020)
	B36	Unclear financial performance over the life cycle	(Bosch-Sijtsema et al., 2021; Ning et al., 2021; Tay et al., 2017)

4. Discussion

The 36 barriers of 3D printing identified in this review are grouped into six (6) main categories:

Group 1: 3D Printing Process and Material-Related Barriers
This category of barriers is related to the physical properties of materials and the printing process itself. Factors such as printability, pumpability/workability, extrudability, buildability, shape retention factor, open time, and scalability are crucial in 3D printing. For instance, some materials may not be compatible with certain printers, while others may require pre-treatment to be printable. Some materials may not be easily workable or pumpable, which could make the printing process more challenging (Guamán-Rivera et al., 2022; Hossain et al., 2020).

Group 2: 3D Printer-Related Barriers
This category of barriers is associated with the 3D printer itself, such as its size, printing rate, and suitability for the digital model being printed. For instance, larger structures require larger printers, which may not be available or affordable. Additionally, some printers may not be fast enough to meet project timelines, which could lead to delays. (Guamán-Rivera et al., 2022; Tahmasebinia et al., 2018) studied the effect of printer size and printing speed on the productivity of 3D printing in construction.

Group 3: Design and Characteristics of 3D-Printed Objects-Related Barriers

This category of barriers is related to the design and characteristics of the printed object itself, such as layer-by-layer appearance, void formation, anisotropic microstructure and mechanical properties, and divergences from the intended design. For instance, the layer-by-layer appearance of 3D printed structures may not be aesthetically pleasing, which could be a barrier to adoption. Additionally, 3D printed structures may have different mechanical properties compared to conventionally constructed structures. Ngo et al. (2018) examined the mechanical properties of 3D printed concrete and identified the challenges associated with anisotropic microstructure.

Group 4: Construction and Site Management-Related Barriers

This category of barriers is associated with the physical construction of 3D printed structures and the management of the construction site. Factors such as cost estimation, construction site setup, logistical challenges, and the size of the structure being printed are critical in this category. For instance, 3D printed structures may require a different approach to construction, which could lead to higher costs. Also, setting up the construction site for 3D printing may require specialized equipment and expertise. (El-Sayegh et al., 2020; Guamán-Rivera et al., 2022; Guamán Rivera et al., 2021) identified the key challenges associated with 3D printing in construction, including construction site setup, full-size of structure and obstacles to the construction site.

Group 5: Environmental-Related barriers

This category refers to barriers related to the environmental impact of 3D printing technology. This includes factors such as the insufficient demand for mass customization in construction, insufficient environmental impact assessment, adverse environmental impact, for example: discharge of harmful substances or emissions, and susceptibility to changes in environmental conditions (García-Alvarado et al., 2020; Jagoda et al., 2020; Ning et al., 2021).

Group 6: Regulatory and Stakeholder-Related Barriers

This category of barriers is related to the regulatory environment for 3D printed structures and the human factor involved in adopting and implementing 3D printing technology in the construction industry. Factors such as lack of codes and standards, insufficient intellectual property protection, need for more competence, reduced demand for workers, scepticism about the potential of 3D printing, and unclear financial performance over the life cycle are crucial in this category. For instance, the lack of clear codes and standards for 3D printing in construction may make it difficult to obtain regulatory approval for 3D printed structures. Stakeholders may be sceptical about the potential of 3D printing, which could lead to resistance to adoption. (Bosch-Sijtsema et al., 2021; El-Sayegh et al., 2020; Jagoda et al., 2020) identified the key barriers to the adoption of 3D printing in construction, including regulatory challenges and stakeholder scepticism.

Key identified barriers

The 13 key barriers of 3D printing are based on the most reported barriers in the selected reviewed literatures, and they are B33, B19, B18, B1, B2, B3, B4, B14, B15, B25, B30, B34, and B36.

B33: Requirement of skilled workers

One of the barriers to 3D concrete printing is that it needs experienced workers with prior expertise in integrating robotic and civil work (Tay et al., 2017). The need for additional skills (in design, manufacturing, materials, testing.) impeding adoption, development skills of current workers, training future generations, consumer education, and educational awareness. However, with the rising acceptance of 3DCP (3D concrete printing), the workforce will require training to cope with the new working procedures of 3DCP or may choose to move to other employment (Mathur, 2016; Tay et al., 2017). According to the workshop result reported by (Bosch-Sijtsema et al., 2021), the participants of the workshop emphasized a lack of competency and the need for training in digital technologies, as well as new competencies that would need to be introduced from diverse disciplines and industries to include new technologies such as 3D printing.

B19: Reinforcement issues:

Another barrier to 3D printing in concrete construction is the difficulty in using reinforcement; since cement components are poured out of the 3D printer nozzle, it is impossible to insert reinforcement within the building. As a result, the tensile strength of concrete becomes a limiting element in constructing a 3D-printed house (Hossain et al., 2020; Sepasgozar et al., 2020; Tahmasebinia et al., 2018). However, with 3D printing, adding steel reinforcement automatically is more complex.

B18: Structural integrity

This is another barrier; since 3D printing models do not have the exact attributes of full-size structures, the structural performance is affected. A good 3D-printed structure depends on the concrete of high quality. However, according to (Berman, 2013), it has been discovered that the quality of printed parts is brittle, making it challenging to print load-bearing components. The multilayer structure is expected to be anisotropic due to the likelihood of voids accumulating between filaments, which impairs structural strength (Buswell et al., 2018). Several studies have revealed that the strength and stability of printed items manufactured using conventional printing materials (plaster) may hinder the technology from being employed in large-scale models or structures (Wu et al., 2016).

B1: Printability

The easiness with which the material is pumped out of the printer's nozzle (Guamán-Rivera et al., 2022; Hossain et al., 2020). The material must be consistently pushed out of the 3D printer's nozzle.

B2: Pumpability/workability

Pumpability is the ease with which the material is pumped through the 3D printer's pump. The pumpability and printability of concrete are greatly influenced by its workability and mix percentage (Uppalla & Tadikamalla, 2017).

B3: Extrudability

The material can be placed in the extrusion system regularly and uninterruptedly (Avinash et al., 2020; Hossain et al., 2020). The nozzle size is critical for concrete extrudability. It is primarily influenced by the mixture's quantity and distribution of dry components, necessitating suitable fine aggregate rheological characteristics (Kosmatka et al., 2008). According to (Lim et al., 2012), the particle size distribution (binder and aggregate) affects the extrudability of printed concrete.

B4: Buildability

The ability of the printed layers to retain the subsequent layers on top of them without failing (Guamán-Rivera et al., 2022). The material to be used in 3D printing must harden fast. Concrete buildability after extrusion results in issues such as lower layer fails, deformations concerning the time gap between layers, and creating cold connections between layers (Guamán-Rivera et al., 2022).

B14: Layer-by-layer appearance

Another barrier is the 3D printing process's layering effect, which generates uneven surfaces with the potential of cavities between the layers. This is one of the 3DCP's significant barriers (Ngo et al., 2018; Ning et al., 2021; Tay et al., 2017). In layer-by-layer deposition procedures, an absence of a compaction method leads to excessive air voids. As a result, the air-void structure in 3DPC is more extensive, which lowers the binding strength between the layers (Nerella et al., 2019). Also, layer-by-layer 3DPC deposition typically results in numerous interfaces caused mainly by air-void presence between succeeding filaments (Wolfs et al., 2019).

B15: Void formation

Sepasgozar et al., (2020) reported that one of the three main barriers to 3D printing is void formation, that is, the availability of voids in concrete. There is the possibility of voids in the layer due to the layer effect of the 3D printing process (Hossain et al., 2020). An entrained air void directly impacts the workability and durability of cementitious materials (Fonseca & Scherer, 2015). Furthermore, the air void between layers will likely weaken the bonding between filaments, affecting 3DPC performance under challenging situations (Ma et al., 2020). For instance, for every 1% increase in air content, high-strength concrete loses around 5% of its compressive strength (Lazniewska-Piekarczyk, 2016). Additionally, the air-void size distribution has a considerable influence on the performance of cementitious materials.

B25: Full-size structure

Another issue of automatic printing of a full-size construction is the danger of losses or accidents if there is an error in the design of 3D models or print settings (Hossain et al., 2020).

B30: Lack of codes and standards regulations

This is also a barrier since there are no defined guidelines for using 3D printing in construction, making it challenging to deploy the technology in a way that conforms with all building codes and regulations (Bosch-Sijtsema et al., 2021;

El-Sayegh et al., 2020; Jagoda et al., 2020). Additionally, defining codes, standards, and specifications for these sustainable structures, especially public safety code requirements, adds to the problems of large-scale 3D printing adoption. The absence of legislation governing 3D-printed buildings presents a barrier for additive-manufactured houses, as any construction activity would be required to follow such a code of conduct in the case of an accident or fatality (Strauss, 2013).

B34: Reduced sustainable employment

One of the barriers to 3D printing is the reduced labour demand due to insufficiently skilled workers in 3D printing (Jagoda et al., 2020; Ning et al., 2021). There need to be more suitably skilled individuals in additive manufacturing and more possibilities for teamwork and idea exploitation (Mehrpouya et al., 2019). As these jobs are replaced by automation, labour force participation rates are expected to decrease.

B36: Unclear Financial Performance over the Life Cycle

There is also a general need to understand the economic benefits that this technology may give. Adding 3D printing to a project's life cycle cost analysis (LCCA) allows an alternate option to be assessed for maximum net savings (Tay et al., 2017).

5. Conclusions and Recommendations

This study presented lessons that have been learned in the previous decade from the selected articles, a systematic review of the literature was conducted, particularly the articles focusing on the barriers hindering the implementation of 3D printing in the construction industry. Those articles were analyzed and discussed. 36 barriers were identified and grouped into six distinct groups. A total of 13 barriers to 3D printing were acknowledged as the key barriers. Due to the rising adoption of 3D printing, it is recommended that existing workers should enrol in training to acquire skills on how the 3D printing system works. The widespread use of 3D printing would result in the loss of numerous construction jobs, particularly in low-skilled occupations. However, the implementation of 3D printing into the life cycle cost analysis (LCCA) of a project allows for the consideration of an alternate option for optimum net savings. This will help in solving unclear financial performance over the life cycle. For the layer-by-layer effect, the impact can be avoided by using thin layers; although, building the entire structure will require extra time and energy. Controlling the air-void structure remains a considerable difficulty. However, adding anti-foaming agents (AFA) can also help reduce unnecessary air-void content in 3DPC. To increase buildability, a square nozzle is commonly used, and it is typically programmed so that the nozzle's orientation is visible to the tool direction. Also, for optimal pumpability, a suitable mix design necessitates a high cement content or, more accurately, a high paste content. Adding more water and 1% to 2% of superplasticizer will make the mix more flowable and improve extrudability. Also, building codes and regulations are urgently required, although some countries are already responding. This review can be useful to scholars and built professionals in helping them to understand the intended barriers which they may encounter, thus knowing how to avoid them.

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Identification of Constraints on Utilizing Energy-Efficient Technological Innovations in South African Warehouses

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Abstract

The pandemic significantly impacted the rapid increase in e-commerce activities, which led to many companies in South Africa needing to develop more prominent and sophisticated warehousing facilities. However, due to the current condition of South Africa's energy supply, the warehousing industry faces many challenges as regular load-shedding interrupts operations. Furthermore, energy-efficient innovative technologies used to reduce energy consumption in warehousing facilities are not widely adopted in South Africa. It was discovered that energy costs contribute a lot to warehouses operating budgets; therefore, the need for energy efficiencies in warehouses is essential. Certain technologies are readily available to be incorporated into South African warehouses to reduce energy consumption. However, implementing such innovative technologies will face many challenges and barriers. This research attempted to identify the challenges and barriers through a constructivist paradigm. The research was conducted using interviews with professionals with vast knowledge and experience in the warehousing industry. The data collection took the form of semi-structured interviews, where a qualitative data approach was adopted. Nvivo was used to generate underlying emerging themes. It was found that only a select few energy-efficient innovative technologies are adopted in South African warehouses and that implementing them provided numerous advantages and disadvantages. Most importantly, the findings revealed a significant number of challenges and barriers to the implementation of such technologies.

Keywords

Challenges, Energy efficiency, Innovative Technology, Warehousing Facilities.

1. Introduction

The warehousing industry is experiencing an opportunity to grow due to the growing popularity of e-commerce, which also boosts the demand for larger warehouses or warehouses with innovative technologies (Rode and Lamprecht, 2021). Due to the pandemic, online retail market growth has accelerated drastically as more people use online platforms to purchase goods. Expanding this industry will result in a greater demand for energy supply; therefore, energy-efficient innovative technology is critical to keep up with increased energy demands. Warehouses may be seen as a burden due to the required capital and operating expenses. According to Martins et al. (2020), warehouse operations represent approximately a quarter of the total logistics cost in the supply chain. Therefore, companies always look to reduce costs and improve energy efficiency in their warehouse operations. Finding the correct balance between using innovative technology to meet tenants' needs and using technology to eliminate the warehouse burden and reduce costs is becoming more critical (Kembro et al., 2017). In recent years, the warehousing sector has been reluctant to adopt energy-efficient innovative technology. Still, due to increasing competition in the industry and cost pressure, technology must be incorporated to gain a competitive advantage. Intelligent Sensors, the Internet of Things (IoT), Artificial Intelligence (AI), Building Management Systems (BMS) and Digital Twins are considered effective means to tackle those problems (Noran et al., 2019).

Implementing these innovative technologies to improve energy consumption addresses the current problem of a lack of environmentally sustainable warehousing (Noran et al., 2019). This is a problem in the South African context as there are national issues regarding energy supply. Therefore, increased effort needs to be put into building energy efficiency. South Africa faces the major problem of load shedding, which costs the economy R20 billion a month

(Akinbami et al., 2021). In addition to load shedding, increased energy prices are causing the cost of production and general building operations to increase. One way of developing sustainable warehouses is through renewable energy sources. A solar warehouse can be developed where the roof of the building is covered in solar panels, reducing energy costs and reducing carbon emissions (Botztepe and ÇEtİN, 2020). Furthermore, alongside the introduction of solar panels, next-generation of building and energy control such as intelligent BMS systems and digital twins can be used to improve energy efficiency. Beyond adding additional sensors and measuring and control systems, innovative technologies can help a warehouse manage energy output. However, the persistent issue is that very little research has been conducted investigating the potential benefit these innovative systems can have in South African warehouses. Thus, this study aims to provide a deep understanding of constraints and challenges in adopting energy-efficient technological innovations to improve the efficiency of South African Warehouses.

2. Literature Review

South African warehouses do not incorporate a wide level of technology, and the technology used is still relatively basic (Magoro, 2019). A key reason is that the South African workforce has not been trained to work with innovative technology. Therefore, the level of highly advanced technology in warehouses in South Africa has not been fully explored yet. As a result, some warehouses will gain a competitive advantage over others as they will be able to fully realize the benefits of technological innovations to save on energy costs (Moghayedi et al., 2022). In today's world, the importance of a solid warehouse facility has intensified due to the increase in the use of e-commerce (Brown, 2020). This was further intensified with the start of the pandemic as consumers were forced to shop online, making warehouse facilities essential to keep up with rising demands. (Brown, 2020). Warehouses are also important to ensure timely delivery to customers (Pedraza, 2021). Warehousing facilities allow businesses to secure their stock, which means their products will be readily available for shipping whenever an order is placed. This eliminates any time wastage and, if managed correctly, will create an opportunity for the business to gain a competitive advantage over its competition (Tien et al., 2019). The population is also increasing rapidly in South Africa, which will ultimately cause an increase in demand for goods and services. Thus, warehouses will become more critical to this rise in demand (Pedraza, 2021). A warehouse can serve as a central location for receiving, storing, distributing, and shipping products from one location, saving transportation costs. In addition, price stabilization is achieved using warehouses which is one of the key reasons warehouses are so important (Tien et al., 2019). The other key reason warehouses are considered important is that they provide a safe location to store perishable goods. A warehouse is where refrigerators and freezers can be installed to store goods at optimal temperatures. This is important for goods such as food and medication as both require cold storage to prevent spoilage and changes in color and texture (Tien et al., 2019). Although warehouses are considered essential and can provide many advantages to those who use them, their performance must be analyzed to understand how the industry has performed over the past few years. According to Brown (2020), the pandemic has rapidly improved the growth potential of South Africa's logistics real estate sector, including the warehousing demand. Furthermore, the recent shift to e-commerce driven by the nationwide lockdown has allowed both existing retailers and smaller e-commerce role players to gear up the scale of operations that have previously not existed in this sector. Furthermore, with the coming of age of e-commerce in South Africa, there is now a focus on supply chains; the pandemic has intensified this, as there is a great demand to have enough space to ensure firms have enough stock on hand to meet sale demands. According to Fortress (2020), there have been a few proposals for new logistics assets requested by retailers looking to enhance their supply chain and who are looking to grow online offerings. Recently, South African investments into the warehousing and industrial sector provide yields of around 9%, often higher than those generated in regions such as Europe, the United States and Asia.

There is a growing consensus among organizations committed to environmental performance targets that appropriate strategies and actions are needed to make all building activities more sustainable (Moghayedi et al., 2021). If done properly, the building industry has a high potential to make a valuable contribution to sustainable development. This would mean that a building must meet several specific objectives, such as energy efficiency. By 2056, global economic activity will have increased by 500%, global production levels will increase by over 50%, and global energy consumption will have increased by 300%. Sustainable warehousing that uses innovative technology to reduce energy consumption has become essential due to the rise of green warehousing and the increase in research on reducing the carbon footprint of supply chains (Lewczuk et al., 2021). Approximately 10% of worldwide CO2 emissions come from logistical supply chains, and around 11% of the total global greenhouse gas emissions generated by the logistics sector are caused by warehousing activities (Carli et al., 2020). Furthermore, the high demand for energy required for heating, cooling, lighting, and material handling equipment in warehouses represents around 20% of overall logistical costs (Carli et al., 2020). Therefore, research into the level of energy consumption of warehouse installations has become increasingly important as it has been considered a good marketing factor as it sends a message to consumers that the business is environmentally friendly; this has been done to create a competitive advantage over other warehouses (Lewczuk et al., 2021). Therefore, the energy consumption of a warehouse is no longer only a cost driver but also something that can be used to market a warehouse and increase its financial performance of a warehouse. However, reducing energy usage in warehouses is important to save money or on marketing actions. It is also a result of legal regulations within South Africa due to the energy crisis.

Eskom Holding SOC LTD is a vertically integrated monopoly that supplies 95% of the electricity consumed in South Africa and 38% across Africa (Akinbami et al., 2021). South Africa is among the highest emitters of CO2, currently ranked twelfth in terms of top emitters per capita, as 75% of its energy supply is from fossil fuels (Höhne et al., 2020). South Africa's solar resource is the third largest globally, and it needs to take advantage of it. In addition to producing unsustainable energy, Eskom is forced to conduct rolling load-shedding to avoid total blackout (Jaglin & Dubresson, 2016). As a result, Eskom has been under severe pressure during peak demand periods and operating the grid in crisis mode (Jaglin & Dubresson, 2016). Furthermore, Eskom's incapacity to meet the country's power requirements, resulting in load-shedding, could force energy users to reduce their energy consumption. From 2021 Eskom has been granted permission to increase average electricity prices to 128,24 c/kWh, which will result in a total annual increase of 15%. However, this may increase by 10% in 2022 (Labuschagne, 2021). In the last three years alone, Eskom has increased the average electricity prices by nearly 25% (Labuschagne, 2021). When South Africa became a democracy, Eskom's average electricity prices were among the lowest. In contrast, between 1994 and 1999, price increases never exceeded the inflation rate, which meant that the actual electricity price was declining (Labuschagne, 2021). However, after load-shedding was introduced in 2008, prices skyrocketed.

3. Research Methodology

Since the study of energy efficiency of innovative technologies in South African warehousing facilities is still a less explored area, it requires utilizing qualitative techniques to collect data from the experts to investigate this little-understood phenomenon as proposed by Creswell and Creswell (2017). Therefore, deploying semi-structured interviews in the present study aimed to provide a basis for conceptualizing the key challenges and barriers to adopting innovative technologies in warehousing facilities. Thus, eight warehouse facility managers and technology experts were identified. As a result, interviews reached saturation point after conducting interviews with six interviewees whose profiles are detailed in Table 1. A thematic analysis of the data collected was employed as this is a commonly used inductive approach to analyzing data. Common themes were identified in the interview transcripts using NVivo, and these themes were used for developing the conceptual framework.

Table 1. Interviewees' profiles

Code	Position	Experience	Organization
A	National Technical Manager	22 years	Refrigerated warehousing across SA
B	Property Development	7 years	International distribution, logistics and operates
C	Property development manager	4 years	Logistical warehousing across SA
D	Facility Manager	35 years	logistical warehousing Across SA
E	Technology expert	8 years	Building automation
F	Chief Digital Director	30 years	Operate and manage large warehousing in SA

4. Results

Examining the data extracted from the transcribed interviews, the following constraints and challenges associated with implementing the use of energy-efficient, innovative technologies emerged throughout:

4.1 High Initial Capital Cost of Technology

When a new building idea is put forward, the client is often over-ambitious and will request all the most recent innovative technology included in the building design but doesn't fully understand the costs associated with some of this technology (Participant C). Therefore, from the developer and design teams' side, they cut out the unnecessary technologies requested and the more expensive technology as often they are not tried and trusted in South Africa (Participant C). There are also trends that the project costs are much higher than initially promised because of the introduction of new technology (Participant F). Participant B, it was stated that *"It depends on what technology you* *use. There are still some technologies where it just doesn't make sense financially."* Therefore, implying that certain technologies have a reasonable initial cost, but other technologies have initial costs that are not competitive. For example, LEDs are considered expensive, but their costs are starting to decrease as technology improves, resulting in their initial costs becoming reasonable for possible installation (Participant D). However, solar panels and batteries to store solar energy are still extremely expensive.

Participant E had differing views on the initial cost of technology than other participants. Participant E stated, *"The innovative technology is the same thing, just a lot cheaper and more powerful."* Participant E said that the initial cost of technology would decrease soon as the technology evolves rapidly and becomes more stable. Furthermore, as suppliers start to push their technology, savings and the initial cost of such technology will improve significantly. Lastly, as technology is improving rapidly, a challenge for investors is that technology often has a turnaround time of 18 months (Participant E). Therefore, it is crucial to ensure that whatever technology is invested in can either be upgraded or that the supplier where the technology was purchased has a 10-year stock on hand due to the rapid turnaround of technology (Participant E). However, the challenge is that suppliers are reluctant to hold old stock. Therefore, if installed systems break down or malfunction, your only options are to upgrade, as the same technology will no longer be available.

4.2 Prevention of Economic Downtime

Some innovative technologies require an installation time, resulting in an interruption in warehouse operations. Therefore, a significant challenge or barrier to entry is preventing any economic downtime or interruption. According to Participant A, the installation of technology may require alteration of the warehouse to install it, or it may need specific spaces to be empty. Thus, the company will have to forgo any income it would generate from that period. If the storage rooms were full, the installation would not have been approved to prevent any interruption in operation. Therefore, only if the stores are empty would it be considered. Participant A stated, *"They don't want to give that money or spend that money and give up that income if they're getting the benefit of using it later."* The key challenge is a trade-off between investing in the warehouse to ensure future savings and losing out on income generated during installation. Thus, further emphasizing the difficulties of guaranteeing corporate approval plans to introduce innovative technology. Participant B stated that they prevent economic downtime in their warehouses by keeping the existing infrastructure in place but building new infrastructure and cutting over to it once it's completed.

4.3 Approvals from Corporate

Due to the relatively high initial costs associated with implementing innovative technology in warehouses, a major challenge and barrier to its implementation are centered around gaining approvals from corporate. Participant A stated, *"Before I spend any money, I need to get it approved. It's all corporate stuff."* Participant A further commented that if the return on investment is less than three years, it will get approved quicker in budget meetings. Participant E stated, *"The owners are always concerned about budgets."* This emphasizes that corporate structures are hesitant to implement innovative technology if it is outside budgetary requirements. Participant D stated that approvals from corporate would only be granted if the specifications align with Health and Safety standards. The recent fires and looting in South Africa have emphasized ensuring the building is a safe space.

4.4 Inappropriate Design and Operations

When the design team receives the task of developing plans for a proposed warehouse often, there is a lack of thought about how the building design has to suit the building's operations (Participant C). Participant C stated, *"At the end of the day, you try to be very clever, but it's tough to be clever enough to think about all these systems and security in buildings."* Therefore, from a user's experience point of view, often, the technology incorporated doesn't suit their needs for optimal operations (Participant C). Additionally, most architects, as that is where the whole project starts, don't ensure the design of the building suits the operations (Participant F). This was highlighted when Participant F discussed the design challenges, *"We still very much work in a traditional project design environment where its Design and Build so the design side doesn't talk to the build side."* Furthermore, the operations team often adopt more advanced technology than the design technology because they must operate the facility.

4.5 Inability to Retrofit Warehouses for Solar

It must be decided from the initial design stages if the warehouse roof will house solar panels. Most of South Africa's warehouses are not designed to accommodate solar panels as the frame is not strong enough to handle the weight of the cells (Participant C). Therefore, it must be decided beforehand if solar power is required. However, if solar panels are considered for installation after initial completion, many challenges and barriers need to be considered. Firstly, the surface area and orientation of the roof must be suitable for solar cells as they must face the sun for a maximum amount of time and be large enough to accommodate the solar panel system (Participant C). Furthermore, the installation will require a professional team to work on the roof, bringing many other risks and challenges. Participant D highlighted a key challenge, *"the last thing you want is some pawpaw to climb your roof, bend the sheeting on the roof, which they will do if they walk around on it, and drill holes in your roof to put a solar installation on."* This situation is challenging because the roof structure's integrity is compromised when they drill holes. The warehouse roof structure also needs to accommodate a cleaning team as most solar cells need to be cleaned regularly as the dirtier they get, the less power they provide.

4.6 Lack of Initial Requirements

A key challenge associated with applying for power is that assumptions need to be drawn regarding how much power is required for the building. Build owners or operators will often overstep their power demands, resulting in the company overpaying for their electricity infrastructure upfront (Participant C). This strategy allows for flexibility as building owners would rather pay extra to ensure their power is not interrupted instead of underpaying and not having the proper infrastructure, which may result in blackouts (Participant C). Therefore, when the initial requirements are drawn up, the challenge is to connect the building to the grid and later, energy reduction plans can be thought of and incorporated (Participant C). Timing is crucial as the earlier you make design changes, the cheaper it is at some point, and it becomes unfeasible to make the necessary design changes.

4.7 Technology Not Tried and Tested

South Africa is far behind in technological innovation as most of the technology incorporated into buildings is imported from Germany and China (Participant D). Participants D and F both emphasized the need for data to analyze energy. However, the data is not readily available in South Africa and is challenging to obtain (Participant D). If data is available, its reliability or accuracy may be impaired, bearing in mind that things change year on year, such as the number of rainy or sunny days and the increase in energy charges across the years (Participant C). However, the key challenge is that the data for energy efficiencies does not exist. Participant D, *"I cannot do a proper energy analysis or risk assessment if I do not have the quality data produced."* A key reason behind the lack of data in South African warehouses may be companies focusing on energy efficiency solutions for typical buildings such as hospitality or residentials but are not experts in refrigeration warehouses, for example (Participant A).

4.8 Dealing with Electricity Provider

Electricity provider in South Africa holds a monopoly in energy supply and production in South Africa (Participant D). However, according to Participant B, it is felt that having a secondary source of power is crucial due to the issues that occur when dealing with this monopoly. *"In our country where we've got load shedding and massive outages, just from maintenance, municipal issues, and cable theft, having some secondary power source or ability to save and run the generator. It's crucial."* Participant B stated that running a facility when load shedding is impossible unless the warehouse has a secondary supply of energy, such as batteries or generators.

When applying for energy supply to a building, the process is characterized by many regulations or hoops. Participant C highlighted the challenges faced when dealing with Eskom, *"You need to apply for power to a building from Eskom, which is a very confusing process that takes much time and it's tough to do because they're a very inefficient entity."* Eskom is stuck in the traditional ways of operating and supplying energy (Participant C). Therefore, if anyone suggests anything inventive or outside the typical operating methods, Eskom will shut down the idea as they are stuck in the old, traditional operating methods (Participant C). This challenge is highlighted as Participant C stated, *"You don't want to do anything out of the box because they will sit 30 people in the room with you, and if you've done anything out of line, they can't handle that. They can't handle anything."* This is a critical problem as it cycles innovation (Participant C).

Eskom's tariff structure is based on time of use. Therefore, when electricity is in high demand in the mornings and evenings, the grid will spike (Participant A). Eskom then charges companies, including warehouses, extra during those periods to force the building to switch off or limit energy consumption so that they can provide energy to the rest of the country (Participant A). Additionally, Eskom charges a company at its highest peak for the month. If the building hits a peak for longer than 30 minutes in a specific time interval, Eskom will charge a bill for the peak demand and the average usage (Participant E). In the past, a BMS system would be able to connect to such intervals to time their energy consumption better to avoid expensive bills. However, Eskom no longer allows BMS to connect to this interval, leaving the system operators to determine when such intervals are manual. This was seen as problematic when Participant E implemented such systems into warehouse space. Additionally, this peak system allows Eskom to charge a building with two bills making it extremely expensive. Furthermore, city councils also charge 30% premiums on power (Participant D). This works because Eskom will manufacture and put energy into the grid, and the council will get their power from Eskom and supply it to the end user. However, the council places a 30% premium when they charge the user for power if they are using power provided by the city council (Participant D).

4.9 Restrictive Legislation

Participant B highlighted a key challenge when dealing with the current restrictive legislation, *"To date, we've had to limit all of our developments to one megawatt."* However, Participant B remained positive as there are plans for the legislation to change to allow a building's producing capacity to increase, which will enable installations to be sized correctly for energy.

Participants B, C and D mentioned restrictive regulatory conditions surrounding solar energy production. Participant B stated that *"the only disadvantage we've had are regulatory. You have to jump through many hoops to get something like solar specifically."* Participant D expanded on this as it was mentioned that during peak times, solar panels could produce more energy than the building can use, which can be recycled into the system. However, the challenge is that there are regulations that state individuals are not allowed to put power into the grid and charge on it. Potential secondary producers of power and city councils are all waiting for the government to enact legislation that will allow people to manufacture their power. Still, the legislation is not yet complete (Participant D). Due to the regulatory barriers that Eskom has in place, warehouses that can house solar panels to substitute a portion of their power cannot provide power to the grid and earn income on it (Participant D). According to Participant D, the law states that if a building is generating power through solar panels and the area has load shedding, the solar panels must be turned off; thus, when the council or Eskom cuts the power supply, the secondary source of power also must be turned off. The government has also been slow with the digital revolution (Participant E). For example, data providers in South Africa are requesting an extra IoT band where all devices with intelligence can join the additional band and transmit data. Participant E said this operation should have been launched four years ago but has not been launched because of the government's restricted legislation.

4.10 Additional Regulations

"Warehouses have to abide by regulations that ensure a certain fresh air flows through the space. Therefore, you cannot completely close the fresh air supply and only use the HVAC system" (Participant E). Presence detectors monitor this, and if there is no presence detected in 45 minutes, the system is turned off (Participant E). Certain warehouses also have strict temperature requirements, such as pharmaceutical warehouses (Participant E). Therefore, there are regulations requiring the HVAC system to ensure temperatures always remain between 22 and 24 degrees Celsius and ensure humidity levels between 40% to 60%. Regulations make energy saving in these warehouses difficult Participant E stated, *"Saving energy in a pharmaceutical warehouse is very difficult because of stringent conditions."* However, these regulations and environmental conditions are in place to minimize the risk of drugs becoming destroyed (Participant E).

"The internal racking and lighting of the warehouse influence each other's performance" (Participant D). Participant D explains the following regulations regarding lighting and stacking requirements; however, these regulations also contribute to improved performance. The best warehouse in the logistics industry will be between 12 and 15 meters in height to the underside of the eaves. The gap between the Aisles can also have a major influence on the level of lighting (Participant D). The height of the racking and the distance between aisles need to ensure 400 lux lighting in the warehouse to comply with the lighting regulations, which is also the optimal level of lighting for a warehouse (Participant D).

5. Discussion

It is evident that adoption levels of innovative technology in South African warehouses are low, with less than half of the participants adopting all available technology. This follows Moghayedi et al. (2022) view of slow widespread adoption levels throughout developing countries such as South Africa. From the findings, it was clear that implementing the technology was to reduce energy consumption; however, following Lewczuk et al. (2021), an apparent reason for this implementation was to ensure competitive advantage and improve marketability and property values. The issues and difficult climate around electricity providers in South Africa were included in the literature review, which surfaced in the findings section. According to Jaglin & Dubresson (2016), the main electricity provider in South Africa is a vertically integrated monopoly that supplies 95% of South Africa's electricity. Still, in recent times the entity has faced many challenges. The findings confirmed this as it was stated that the electricity provider held a monopoly on energy supply and production. The challenges faced by South African electricity provider was also highlighted in the findings, as it was stated that it is crucial to have some secondary source of power in South

Africa due to the challenges associated with load shedding, municipal issues, cable theft and poor maintenance services. The findings confirmed that electricity providers in South Africa are inefficient entities, and dealing with them is a challenge. However, there are plans to become less reliant on a grid using renewable energy.

The South African government wants to adopt a more renewable energy supply by 2030. The aim was to generate 42% of its electricity from renewable sources (Craig et al., 2017). This goal surfaced once the findings were investigated, as it was stated that the city councils and potential secondary producers of power are waiting for the government to enact legislation allowing people to produce their power, thus confirming that there are plans to move to a renewable energy supply plan. A key method to produce renewable energy in South Africa is solar panels. However, challenges and implementation considerations must be fully understood before installing solar panels. The findings stated that certain warehouses could not house solar panels as from the initial design stages, it has to be decided if warehouses will be installed. Hence, the roof can hold them. Furthermore, the surface area and the orientation of the roof must be suitable for solar panels, which confirms Boztepe & ÇEtİN (2020) statement that only some warehouses can house solar panels.

Implementing innovative technology will challenge its entry into the property market (Green et al., 2022). According to Dadzie et al. (2018), the cost of technology is a major barrier for investors, confirmed in the findings as the interviewees mentioned that the high cost of implementing innovative technology is often the reason corporates reject the idea. Additionally, the results confirmed that some technologies did not make sense financially to incorporate into warehouses. Jobber et al. (2019) mentioned that property professionals are unaware of its benefits due to the poor salesmanship of companies selling such innovative technologies. This is confirmed in the findings as the interviewees mentioned that data about the benefits of such technology is not readily available in South Africa, thus deterring them from using it in their warehouses. Moghayedi et al. (2022) stated that a barrier to entry is that technology often needs to be replaced, which may lead to the replacement of the entire unit. The findings mentioned that a key disadvantage was that technology installed in a warehouse is susceptible to upgrades if a sensor or two fails, which may lead to the entire system failing, thus requiring an upgrade. These replacement costs are a significant barrier to entry as over and above the initial cost of innovative technology are the replacement costs that may arise.

Lastly, the findings confirmed that only a few companies in South Africa were doing proofs-to-concept of developing strategies to incorporate technology. The participants confirmed that a lack of awareness and data is another barrier to adopting innovative technologies in the warehousing industry in South Africa. Furthermore, the technology is too expensive and not being tried and trusted.

6. Conclusion

Even though the study proved the potential of innovative technologies in improving warehouse facilities' energy efficiency, various challenges and barriers must be overcome before such technology is installed in warehouse facilities in South Africa. It can also be inferred from the study findings that the major challenges and barriers include approvals from corporate, as due to the high initial cost of implementing innovative technology, corporates are hesitant to invest in it. Additionally, the economic downtime which may arise during installation was a major barrier to entry. Other challenges and obstacles that were identified relate to the design and building. Often, the users of a warehouse face issue that arise after implementing innovative technology as the design side does not work with the build side. Lastly, various challenges and barriers are associated with the current energy supply in South Africa as the electricity provider holds a monopoly in energy supply but is an incredibly inefficient entity facing many issues, such as their inability to supply stable energy to the country. A key solution to this would be to allow for secondary power producers. Still, there is restrictive legislation surrounding renewable energy production, thus making it illegal to produce and sell your power. The hoops people need to jump through to implement innovative technology to produce their power supply is one of the major challenges and barriers preventing the adoption of innovative technology in South African warehouses. To enhance the adoption of innovative technologies in warehouse facilities in South Africa and therefore improve the energy efficiency in these facilities, there should be more guidance and incentives from relevant authorities in South Africa.

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Development of a Cashflow Model for Monitoring Hospital Project Performance

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Abstract

Hospital projects, given their unique characteristics and features, are distinct from other types of construction projects. The development of hospital projects faces several challenges due to rapidly changing user requirements, multiple healthcare policy frameworks, and complexity of process. To keep success rates high, there is a need to support project management efforts and decisions with appropriate monitoring and control tools. This study develops a cashflow model for monitoring the performance of hospital projects in the construction industry of Hong Kong. The normalization and percentile techniques were integrated in analyzing the monthly cashflow data of public hospital projects completed in the past 20 years and constructing the model. The model provides alerts for three types of project performance, namely, green (or normal), yellow, and red performance. It helps in foreseeing existing or potential challenges in ongoing hospital projects and providing early warning signals for corrective actions to be taken effectively and in a timely manner. This study contributes to the Project Management Body of Knowledge by developing a model for enhancing hospital project delivery.

Keywords: Hospital projects; project management; project performance; monitoring and control; performance modelling; cashflow model; construction industry; Hong Kong.

1 Introduction

The pace of population aging has been ramping up in the past years in Hong Kong. According to the "Hong Kong Population Projections 2020-2069" released by the Census and Statistics Department of the Hong Kong SAR government (C&SD), the population aged 65 and over accounted for 18% of the overall population in 2019. Furthermore, the aging trend in Hong Kong will continue to accelerate in the future. It is estimated that there will be 2.58 million older people in 50 years, accounting for 38.4% of the total population in Hong Kong (C&SD, 2020). The aging trend will be accompanied by increasing healthcare needs. Currently, it requires a concerted effort across industries and the government to provide adequate healthcare services to all residents in Hong Kong. To cope with the challenges of the aging population and satisfy growing healthcare needs, the Hong Kong SAR government has formulated two 10-year hospital development plans costing about US$64 billion to upgrade, expand and develop healthcare facilities (International Trade Administration, 2022). In 2016, the Hong Kong SAR government set aside a dedicated provision of HK$200 billion for the implementation of the first 10-year hospital development plan (HDP) in the coming ten years; the 10-year HDP comprises construction of one new acute hospital, redevelopment and expansion of existing 11 hospitals, construction of three new community health centres and construction of one new supporting service centre (Hospital Authority, 2016). Subsequently, the government planned the second ten-year HDP in 2018, and several hospital projects have been included in the second ten-year HDP to boost its inpatient capacity, enhance service quality, and renew its building facilities (Legislative Council Panel on Health Services, 2019). Compared with general projects, hospital construction projects require more complex functions and stronger professionalism. Moreover, hospital projects also face various challenges, such as long construction periods, enormous investments and multiple stakeholders. The complexity, uniqueness and challenges may endanger the ultimate success of hospital projects. Cost and time are critical parameters of hospital projects and driving forces of success. However, in addition to time overrun, cost overrun is a common phenomenon and associated with nearly all projects in the construction industry (Azhar et al., 2008). Apart from construction factors, the major reasons for delays and cost overrun in the public projects of Hong Kong include funding approval delays, the need to re-design, inclement weather conditions, and deployment of additional resources to deal with other unforeseen circumstances etc. Effective cost and time control can decrease the hazards of failing to deliver hospital projects. Monitoring the cashflow is crucial in cost control for the project success. Nevertheless, specific methods of monitoring cashflow of hospital projects are relatively limited. Hence, it is necessary to develop an effective tool for monitoring the cashflow of hospital projects, which enables stakeholders to predict potential problems in the implementation period and provide early warning signals for early intervention. This study aims to develop a cashflow model for monitoring the performance of hospital construction projects to provide an effective tool for stakeholders to deliver hospital projects successfully.

2 Literature Review

2.1 Development of Healthcare Projects in Hong Kong

In the initial period, healthcare services of Hong Kong were mainly provided by charities. In 1872, Tung Wah Hospital, the first private charity hospital in Hong Kong, was founded with the support of Chinese pioneers. People's growing medical demands constantly stimulate the dynamic development of healthcare projects. In 1894, an unprecedented plague pandemic in Hong Kong killed more than 2,000 people of Hong Kong and forced a third of the population there to flee. In 2003, SARS swept through Hong Kong. Furthermore, Hong Kong has been encountering the challenges of various epidemics, such as the Middle East Respiratory Syndrome (MERS), influenza pandemic, Ebola virus disease, Zika virus infection, Dengue Fever, COVID-19, and Monkeypox. There is a large elderly population in Hong Kong, with 1.27 million people over the age of 65 vulnerable to severe COVID-19. Simultaneously, considerable number of residents face the threats of various diseases in Hong Kong, especially the elderly group. Healthcare services in Hong Kong have been under extreme pressure with the spread of a series of infectious diseases and other chronic diseases of the elderly. Subsequently, a variety of healthcare services of Hong Kong have been developed for satisfying the healthcare needs of the public, such as primary medical care services, hospital services, tertiary and specialized services, elderly, long-term and rehabilitation care services, integration between public and private sectors, and infrastructure construction (HKGovernment, 2005). However, over the past decade, increasing hospital floor space per bed was offset by declining hospital beds per population. According to statistics from the Hospital Authority, the number of hospital beds per capita in Hong Kong has generally dropped from 4.94 to 4.07 per 1,000 people. To solve this asymmetrical problem, the construction, reconstruction and expansion projects of hospitals are in process to enhance healthcare services.

2.2 Characteristics of Healthcare Projects

Healthcare projects are complicated, in accordance with rigorous security measures, strict sanitary conditions, procurement of special medical equipment, and complex requirements for managing large databases (Sebastian, 2011). As a healthcare facility, it needs to meet the accommodation and clinic requirements, guarantee operational efficiency, conform to aesthetics standards, and facilitate practical use. Javed et al. (2013) illustrated that the hospital project requires a comprehensive functional demand, including sustainability, accessibility and safety. The hospital project is supposed to follow the principles of "green building system", which means it ought to create green indoor and outdoor environment, save energy consumption, use environmentally friendly materials and equipment, utilize new construction technologies, and reduce the pollution of air, water and waste. Patient-oriented design is also the focus of hospital projects. This design is embodied in various particulars, such as the functional design of buildings, decoration, supplementary healthcare facilities, medical equipment and so on. Moreover, hospital projects have attached much importance to intelligent and automated systems, which are different from general construction projects. The current hospital requires diverse information management, integrating common management systems, high-standard medical data systems, as well as specific image processing systems for radiology, ultrasound and speculum. The requirement for automatic management of medical equipment and dynamic security management system is also a significant feature of hospital projects. The cashflow patterns of healthcare projects are quite unique because of the high furniture and equipment (F&E) cost allocation to largely meet the abovementioned requirements. These unique cashflow patterns have implications for the performance of healthcare projects as compared to general construction projects. Essentially, the complexity and uniqueness of healthcare projects create challenges for the successful delivery of those projects.

2.3 Definition of Project Success

Stakeholders tend to pay great attention to the project success. The success of a project is achieving pre-planned goals, and it's also the ultimate goal pursued by stakeholders. The project success is always regarded as a combination of specific and subjective goals listed in the success criteria. The success of a construction project, which is generally considered as being accomplished on time, within budget and meeting quality requirements, is featured to achieve many preferred outcomes over the usual demands (Adaurhere et al., 2021). Wahaj et al. (2017) deemed that the project success ought to meet clients' requirements and obtain their satisfaction. Additionally, sustainability and conforming to the specifications are also parts of the criteria of project success. However, the criteria of project success are controversial and difficult to pin down. Although various approaches to determining project success have existed, they are almost on the basis of the iron triangle of time, cost and quality. Nonetheless, the success of any construction project cannot be limited to the scope of the iron triangle. Currently, the multi-dimensional framework plays a critical role in assessing the project success, integrating the traditional iron triangle, effective resource management, quality and stakeholder satisfaction (Kimaru, 2019). Nevertheless, the terminology project success is fundamental to managing and controlling current projects so as to plan and guide future projects.

Time criterion is essential in construction projects in Hong Kong because the jurisdiction of Hong Kong has gained a good reputation for excellent speed when carrying out construction projects. Studies have shown that construction projects in Hong Kong have undergone high-cost upgrades. Cost and time criteria have been studied as interrelated concepts in projects, which meet the conventional definition of project success as within the budget and deadlines specified in the contract (Larsen et al., 2016). Planning for time and cost prior to design and construction stages contributes to improving user satisfaction, reducing project duration and cost, hence advancing the success of project.

2.4 Role of Project Monitoring

Project monitoring involves tracking the project's performance indicator, progress, and associated tasks to ensure that a project is completed on time, within budget, and meeting quality requirements and proposed standards to achieve its successful delivery. Project monitoring can contribute to identifying obstacles or problems that may arise during project execution so as to allow stakeholders to take action to cope with these issues in time. Project success usually relies on effective and dynamic project monitoring. Effective project monitoring enables project managers to gather valuable data of project progress and utilize the collected data to make informed decisions. Collaborative forecasting of cost and time is a crucial tool for effectively monitoring, controlling and managing projects from inception to completion. Large variances in cost and time can significantly affect the cash flow, profitability and viability of a project. Hence, it is necessary for project managers to forecast these variances and make the prediction accurate in early stage to deal with various issues involving stakeholders and financial planning, which facilitates the successful project implementation (Li et al., 2006). Especially in the construction industry, project managers believe that predicting the cost of completion is the most important function of project control technology (Kim et al., 2003). It is vital for project managers to skilfully predict the amount of deviation from the original budget of a project.

2.5 Relevance of Cashflow Forecasting

Project cashflow has attracted the widespread concern from both contractors and clients. Adequate cashflow is necessary to achieve three fundamental goals in project management. Firstly, the sufficient cashflow contributes to covering the costs in terms of management, material and labour for the project. Secondly, the ample cashflow is needed to decrease the financial liabilities that the company may have to assume during the project implementation. Additionally, adequate cashflow is key to executing construction activities on schedule, as cost and time are interdependent parameters (Al-Joburi et al., 2012). In summary, the effective management of cashflow is pivotal to the profitability and survival of any construction enterprises. As the project progresses through various phases, contractors are supposed to try to avoid taking on work under additional loads without regard to schedule requirements. Hence, it is important for contractors to ensure sufficient cashflow before meeting schedule requirements (Al-Joburi et al., 2012). The ineffective construction financial planning can lead to significant escalations of cost and schedule, which may extend to the financial collapse of the entire construction project. From the perspective of clients, cashflow forecasting is the basis for their commitment to pay contractors on time at the appropriate stage of the project. To ensure timely payment and keep contractors working, clients need to forecast cashflow accurately to drive the project implementation. Ultimately, appropriate monitoring and control of cashflow will contribute to the successful delivery of projects, hence the satisfaction of clients and other stakeholders.

A variety of methodologies have been used for forecasting cashflow to monitor the project performance. Some forecasting methods exhibit high-degree inaccuracy in terms of strategic misstatements and optimistic biases, such as baseline estimation, Monte Carlo simulation, and earned value management. For instance, the average inaccuracies of cost forecasts for transport infrastructure projects are 20.4% for roads, 33.8% for bridges and tunnels, and 44.7% for railways (Flyvbjerg, 2008). More advanced methods are being developed to overcome these prediction problems in projects.

3 Research Methods

As can be emphasized, different types of projects exhibit distinguishing characteristics and features as well as performance norms. Hospital projects are of special characteristics and differentiated from other types of construction projects by their complexity regarding the (1) dynamic interactions of systems, subsystems and elements; (2) massive quantity of information and requirements; (3) high degree of changes and change management; (4) evolving conflicts and interactions between healthcare legislations and policies and hospital project requirements; and (5) diverse, multiple and complex healthcare policy frameworks issued in fragments over time (Soliman-Junior et al., 2021). Hospital projects may similarly possess these features and characteristics particularly when developed in the same geographical jurisdiction. Therefore, it is logical and reasonable to develop a singular cashflow model for the purpose of evaluating, monitoring and controlling hospital project performance in Hong Kong. The cashflow model is meant to emphasize the famous relationship between cost and time on the performance of hospital projects. The study employs a purely quantitative approach to analyze the cashflow dataset of completed hospital projects.

3.1 Data Collection and Preparation

The focus of the study is on the public sector and so cashflow dataset of hospital projects completed in the past 20 years under the Capital Works Programme was obtained from the Development Bureau of the Hong Kong SAR. A number of measures were put in place in order to make the cashflow dataset appropriate and reliable for analysis. This further ensured that the real cost-time settings of the hospital projects were properly incorporated into the cashflow dataset for analysis. The measures employed include: (1) eliminating hospital projects with incomplete and/or irrelevant cashflows from the dataset to avoid contamination, (2) retaining only hospital projects with durations of more than two years in the dataset, (3) compiling all hospital project cashflows in the dataset on monthly basis for easy analysis, (4) using the substantial completion dates as the common criterion for determining the completion durations of all hospital projects. Substantial completion is "*the time or date when the entire construction, or a designated portion thereof, is sufficiently complete such that the construction can be occupied and used by the owner for its intended purpose*" (Nabi et al., 2021). Out of a population of 43 public hospitals and institutions in Hong Kong (Hospital Authority, 2023), the cashflow dataset of 19 hospital projects meeting the abovementioned criteria was obtained for analysis. Other project information obtained includes project name, budgeted costs, actual costs, planned durations, final durations, start and finish dates, etc.

3.2 Data Analysis Process

To fully analyze the hospital project cashflow dataset and develop the cashflow model, the process followed is explained in the following subsections.

3.2.1 Normalization of Cashflows

Normalization is the process of developing standard durations or data points to allow for several hospital projects of different durations to be acceptably compared on the same basis. Thus, instead of developing a number of month- or year-based cashflow models for different durations in normal circumstances, a singular stage-based cashflow model developed with the help of normalization is adequate to perform the same monitoring function. The usefulness of normalization in this study includes the: (1) prevention of potential false alarms at the early stages of hospital projects due to the cumulation of cashflows in the model, (2) ease of conducting like-with-like comparisons of several hospital projects with just a singular model, and (3) potential of organizing several cashflows of hospital projects into a singular powerful database in a more consistent and flexible manner. Normalization is noted to be a potent method for resolving and organizing similar distributed project information in past studies (e.g., Development Bureau (2018a)).

Since the durations of the 19 hospital projects are different, it is important to normalize the durations into equal standard stages by using the substantial completion dates as the common factor. This enables the cashflow performance of hospital projects with different durations to be easily and logically compared. Essentially, the normalization method divides the substantial duration (i.e., from the start date to the substantial completion date) into ten successive equal stages and then sums up the respective monthly cashflows within each stage. Equation 1 is the formula engaged for calculating the cumulated cashflows for the X^{th} one-tenth stage of the substantial durations.

$$Q_{SX} = \sum_{Y=1}^{t} Q_Y + \left[\left(\frac{n}{10} \times X\right) - t\right] \times Q_{t+1} - \sum_{Z=0}^{X-1} Q_{SZ}$$

Equation 1

where, $\left(\frac{n}{10} \times X\right) - 1 < t \leq (\frac{n}{10} \times X)$ and t is a positive integer, n is the project duration in months, Q_t is the amount of cashflow in the t^{th} month, Q_Y is the amount of cashflow in a particular month, Q_{SX} is the total amount of cashflow at a particular stage, Q_{SZ} is the total amount of cashflow at any prior stage, and $Q_{S0} = 0$.

After obtaining the stage-wise cashflows, it is necessary to cumulate them forward-wise from stage one to stage ten. Therefore, Equation 2 is utilized for computing the cumulated cashflows from the project start date up to the X^{th} one-tenth stage of the substantial durations.

$$Q_{TX} = \sum_{X=1}^{10} Q_{SX}$$

Equation 2

where Q_{TX} is the sum of all cashflows up to X^{th} stage, and Q_{SX} is the cashflow at a particular stage of project.

At the next stage, the relative proportion of each cumulated cashflow at the X^{th} one-tenth stage of the substantial duration to the final project cost (i.e., Q_{PX}) is obtained using Equation 3.

$$Q_{PX} = \frac{Q_{TX}}{Q_T} \times 100\%$$

Equation 3

where Q_{TX} is the sum of all cashflows up to the X^{th} stage and Q_T is the final cost of the project.

3.2.2 Development of Cashflow Model

The graphical cashflow model is developed to express the true standard relationship between the normalized durations and cumulated cashflows of hospital projects. In effect, it will serve as a standard tool to check the cashflow performance of hospital projects. The cumulated cashflow percentages at the ten normalized stages for all hospital projects are compiled, and specified percentiles of the cumulated cashflow percentages are extracted for developing the model. The model comprises four different cashflow patterns that demarcate the boundaries of three performance and risk zones. Cumulated cashflows of new hospital projects falling within these zones will provide quick performance and risk alerts for project managers and decision-makers to investigate existing or potential underlying problems and take corrective managerial actions where necessary. The objective is to ensure that about 70% and about 95% of the cumulated normalized cashflows are found between the two inner patterns and the two outer patterns respectively (Development Bureau, 2018b). The explanation supporting this approach is that project cashflows that are closer to the median cashflow pattern are of better performance, and vice versa. Accordingly, the 2.5th, 15th, 85th and 97.5th percentiles are calculated for the cumulated normalized cashflows at the individual stages by using Equation 4.

$$P_i = \left(\frac{i[n+1]}{100}\right)^{th} \text{ item in the ascending list of values}$$

Equation 4

where P_i is the ith percentile of the list of cumulative normalized cashflows at a particular stage and n is the sample of projects in the category under consideration.

4 Results and Discussion

The dataset reveals significant ranges of the final costs (i.e., about HK$200M to HK$8,800M) and actual durations (i.e., about 18 months to 108 months) of completed hospital projects. It is observed that the hospital projects perfectly experienced cost underruns of as much as -33% and an average of -17%. Some hospital projects however experienced time overruns. Generally, hospital projects in Hong Kong are executed within the original budgeted costs whereas some overrun their planned durations. The sample properly captures different scopes, scales and complexities of hospital projects to cover the known unique characteristics and features.

The normalized cashflow model of the hospital projects is illustrated in Figure 1. The normalized cashflow model terminates project expenditure at the substantial completion dates, and hence, the curves are not expected to reach 100% of expenditure. The rest of the project expenditure is made in bits and less consistently over a very long period after the substantial completion date because the major works are already completed. The percentile curves linking the cumulated normalized cashflows in the model provide an avenue to divide cashflow performance of hospital projects into zones. By interpretation, each performance zone manifests a matching potential risk of overrun that should be investigated to inform on specific corrective actions in projects. Whereas the green zone indicates the least risk of overrun, the yellow zones show the medium risk of overrun, and the red zones point to the highest risk of overrun in terms of cost and time performance. Particularly, the cumulated cashflow of a new hospital project falling into the upper yellow and red zones means the potential of cost overrun than time overrun occurring, whereas falling into the bottom yellow and red zones indicates the likelihood of time overrun than cost overrun happening. It is only when the cashflows of new hospital projects fall within the green zone that project managers and decision-makers can assume that all is well regarding cost and time performance. Otherwise, an investigation should be carried out on project experiences to disclose any foreseeable underlying problems and subsequently apply corrective measures in projects.

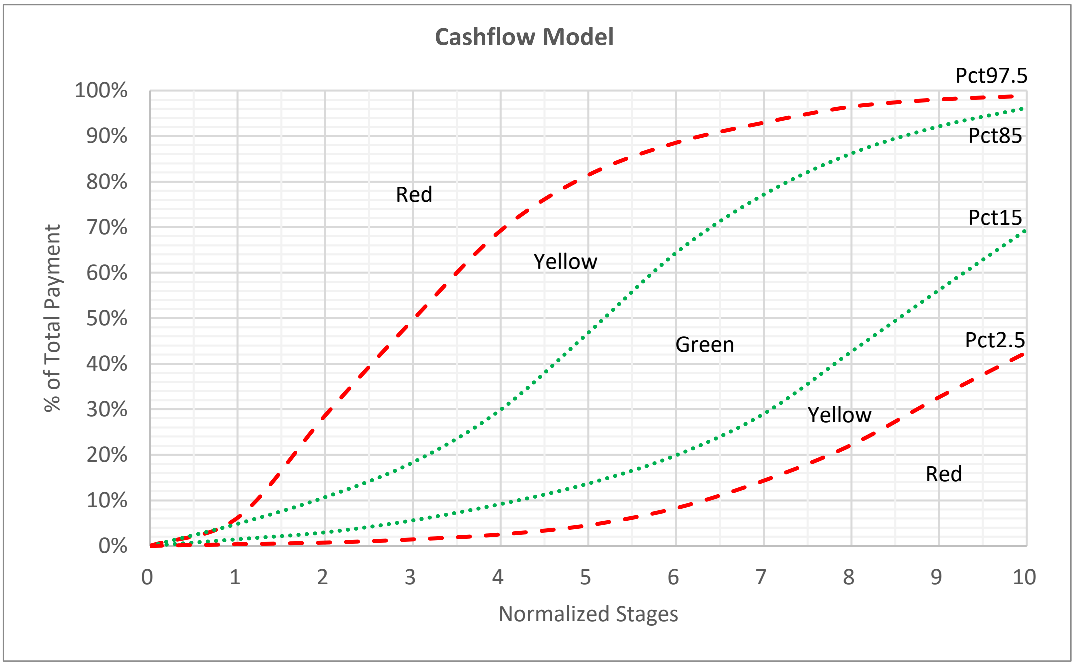

Figure 1: Cashflow model for hospital projects

Although specific cashflow models of hospital projects are lacking in literature of contemporary times, cashflow models of other types of projects or general projects have been proposed. For example, Mills and Tasaico (2005) developed two polynomial regression models using time and project attributes to estimate monthly cashflow for 336 transportation design-build projects completed in North Carolina. The developed regression model does not show reasonable accuracy beyond a 12-month forecasting horizon (Liang et al., 2021). Ock and Park

(2016) developed an algorithm for forecasting cashflow of a construction project in the planning stage according to daily cashflow. This algorithm considers factors such as time lags, cost categories and the cost category weight on earned value and budget. Nevertheless, the applicability of this cashflow forecasting algorithm hinges on further validation. Cheng et al. (2020) put forward a model using the deep learning technique for forecasting cashflow of construction projects. This model relies on independent variables and time-dependent variables, and the independent input variables representing project complexity include the number of floors, contract costs, floor area, and project duration. It may be considered as a great model for forecasting future cashflow of construction project to some extent, while it turns out to be complicated due to the complexity of using deep learning technique in practice. Moreover, it requires a large amount of data of real cases for training the model, which increases the difficulty of applying this model. Msawil et al. (2021) developed a heuristic cash flow forecasting model for infrastructure projects. This model offers detailed assessment of the potential behavior of the cash flow trends at both the resource and work package levels, which can be served as a tool for practitioners to forecast the cashflow of infrastructure projects. Despite the contribution, it cannot be fully generalized to other types of projects. Weytjens et al. (2021) compared different cashflow forecasting models and disclosed that some classic cashflow forecasting techniques such as ARIMA and Prophet were limited in terms of flexibility and accuracy of prediction.

In contrast, the cashflow model developed in the current study is a specific model that will provide better monitoring and forecasting functions in hospital projects than the aforementioned models. It provides a good basis for all hospital projects to be equally monitored and forecasted by the normalization of monthly and yearly durations into stage-based durations. Thus, it can reliably monitor and forecast several ongoing hospital projects with different durations at the same time for comparison and benchmarking purposes, which considerably enhances its usefulness and flexibility in practice. Following the normalized duration approach, the accuracy of the cashflow model in monitoring and forecasting should be about equal for short-term, medium-term and long-term hospital projects sharing similar features and characteristics. Another important attribute of the cashflow model that fills research gap is that it somewhat analyzes the level of risk regarding time and cost problems in hospital projects by the indication of green, yellow and red alerts. From a practical perspective, the cashflow model is more effective in terms of detecting existing or potential problems in hospital projects and providing early warning signals to project managers and decision-makers. The study innovatively adopted the method integrating normalization and percentiles to develop the cashflow model. This integrated method is unique because of the simplicity of normalizing cashflows, extracting the percentile-based cashflow patterns, and constructing the cashflow curves to model different performance zones. As more hospital projects are completed and the underlying database expands, then the accuracy of the reconstructed cashflow model in monitoring and forecasting ongoing hospital projects will significantly improve. Besides, basic know-how of mathematics and graphing tools (e.g., Microsoft Excel) will enable researchers and practitioners to adopt the method in developing applicable cashflow graphs for monitoring different project types with common attributes e.g., railway, tunnel, road and school projects.

5 Applications of the Cashflow Model

The cashflow model is useful for several reasons including comparison, benchmarking, evaluation, monitoring, controlling, forecasting and enhancement of hospital project performance.

5.1 Comparison and Benchmarking of Performance

A major function of the developed cashflow model is to provide a good basis to compare several hospital projects with different durations. When the durations and cashflows are maintained in the original monthly formats, comparing projects with different completion durations will be difficult and questionable. This is because several cashflow models would be needed to monitor the performance of multiple hospital projects with a wide range of completion durations. However, the normalization process solves this problem by ensuring that all projects could be equally stretched over ten duration stages up to their substantial completion dates for easier comparison. The developed cashflow model is more inclusive, flexible and effective, and it emphasizes like-with-like comparisons of an unlimited number of hospital projects in Hong Kong.

5.2 Evaluation and Monitoring of Performance

By evaluating a new hospital project with the model, the present status, immediate future status, and completion status of performance could be known with a significant level of confidence. The cashflow performance correlates not only with the durations exhausted but also with the work packages completed in hospital projects. Adverse evaluation results mean hospital projects are likely to experience cost and/or time overruns, whereas positive evaluation results imply that hospital projects would conceivably remain within cost and time targets. Three hypothetical projects, A, B, and C are presented in Figure 2 to illustrate how the developed cashflow model can evaluate, monitor, and control hospital project performance. Project B has maintained cashflow performance in the green zone after stage one, Project A has largely alerted cashflow performance in the yellow zone, and Project C has its cashflow performance changed from the yellow zone to the red zone. By implication, Projects A and C show moderate and high risks of cost and/or time overruns occurring. Specifically, Project C manifests that there is probably (1) underpayment for work packages completed so far, (2) back-end loading such that major work packages are scheduled to be completed in the tenth stage, (3) series of minor work packages to be carried out after the substantial completion date, or (4) insufficient substantial duration to accomplish all main work packages. With this background knowledge, project managers and decision-makers are guided in implementing necessary measures to monitor and control the progress of these hospital projects in order to realize set targets. The underlying causes of the problems experienced in hospital projects are not directly revealed by the evaluation results. The results only point to the fact that the hospital projects are experiencing problems that need to be investigated. The investigation will reveal underlying causes such as technology failure, ineffective coordination of activities, unforeseen ground conditions, payment problems, poor resource quality, change in design, material shortage, variation orders, land acquisition and readiness, ineffective cost and schedule control, complexity and complication, inflation and exchange rates, worker turnover, execution mistakes, and contractual problems.

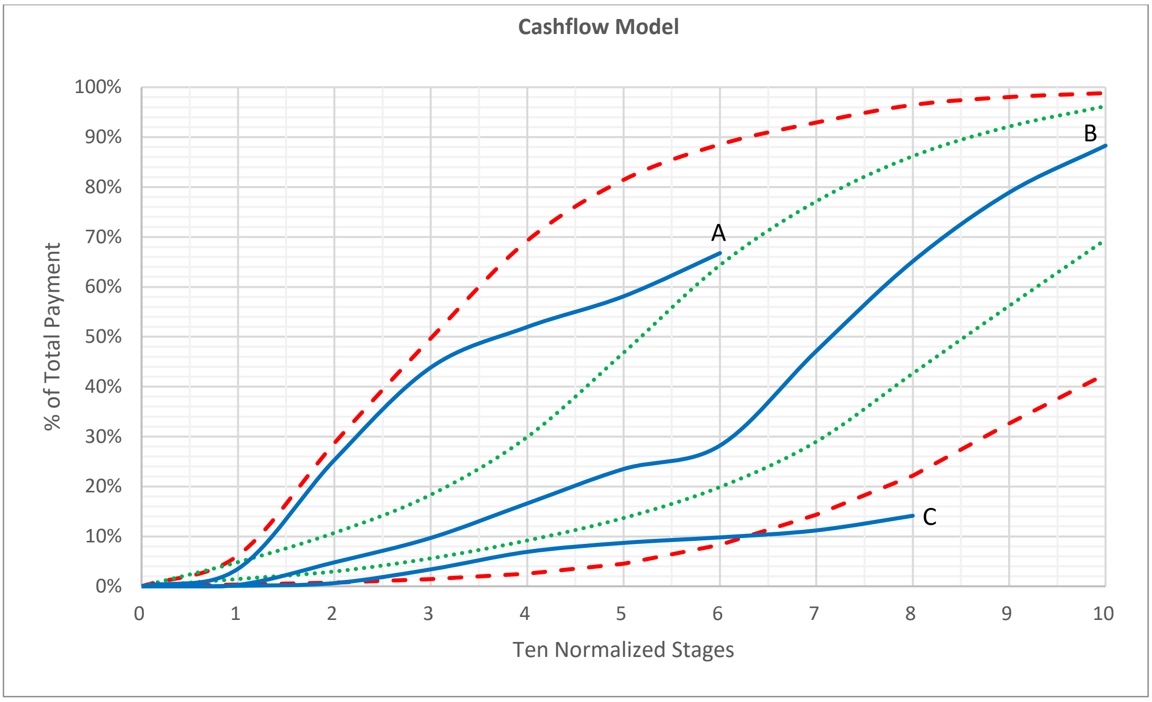

Figure 2: Demonstration of evaluation and monitoring of performance

5.3 Enhancement and Forecasting of Performance

Additionally, the cashflow model is helpful in enhancing and forecasting the cashflow performance of hospital projects. Upon identifying the specific problems troubling hospital projects, project managers and decision-makers must take corrective measures to restore cashflow performance to the green zone as much as practicable. The corrective measures are expected to help enhance the performance of hospital projects in terms of cost and time. For instance, when unexpected ground conditions cause the cost of excavation, ground preparation and other works at the early stages to exceedingly increase, there would be overpayment for these works as compared to the initially available budgets. By revising and increasing the available budget to a commensurate level, the cashflow performance of the project will return to the green zone. Figure 3 presents a revision to the cashflow performance of three hypothetical projects A, B and C upon the application of corrective measures where necessary. Project A initially experienced overpayment for the work packages completed so the project budget is increased by about 60% and this returns its cashflow performance to the green zone. Project B requires no corrective measures, and it is left in the original experience of cashflow performance in the green zone. Project C is granted a 100% extension of time, and this upgrades the cashflow performance to the green zone. Note that the corrective measures are implemented only for the sake of demonstration and clarification.

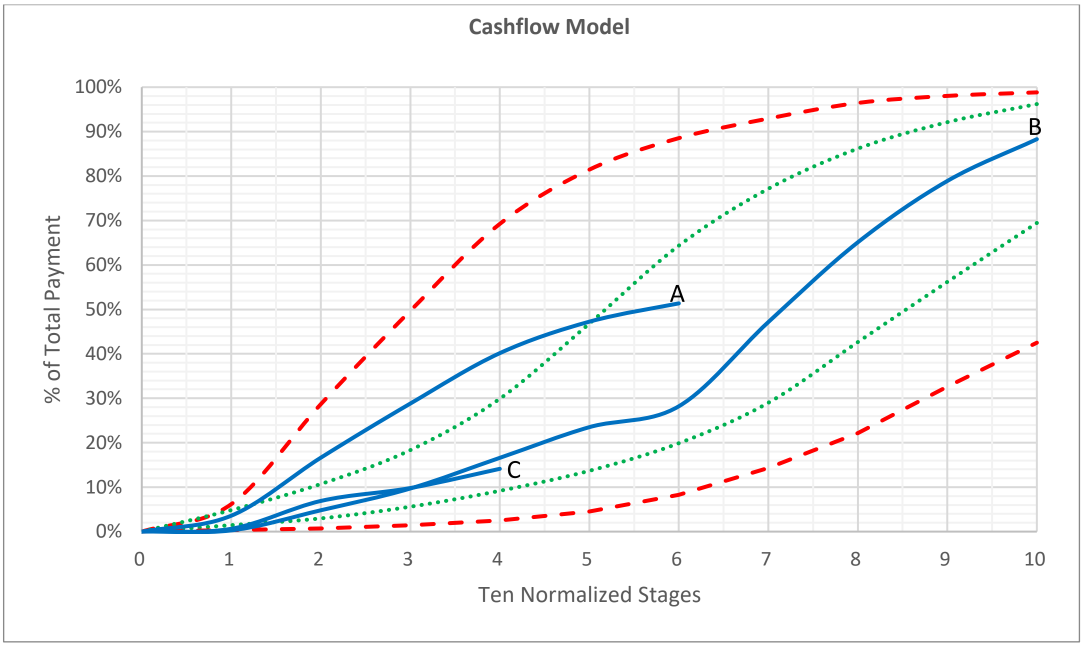

Figure 3: Demonstration of enhancement of performance

Figure 4 indicates the use of the cashflow model for the purpose of forecasting the cashflow performance of Projects A and C. Project managers and decision-makers can follow the model's expectations on cashflow performance as well as the project objectives to restructure work package schedules and predict acceptable cashflows accordingly. Whereas the solid lines show the actual cashflows, the continuing dashed lines show the forecasted cashflows of Projects A and C.

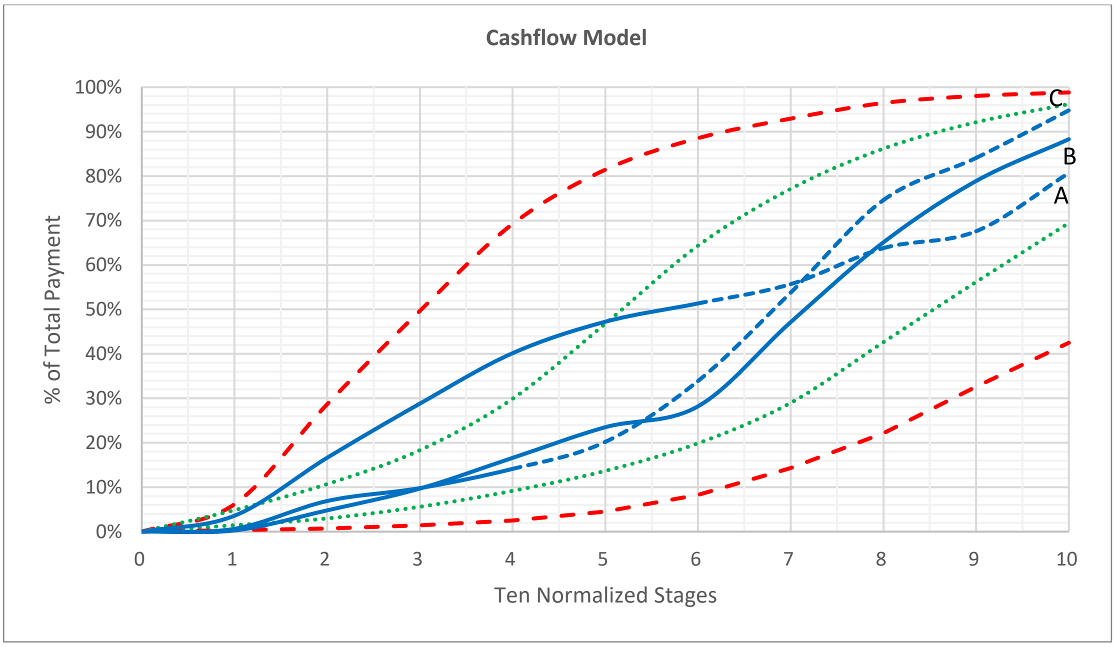

Figure 4: Demonstration of forecasting of performance

6 Conclusion and Limitations

Hospital projects are unique among the several types of construction projects because of their special characteristics and features. The development of hospital projects is very challenging and requires great project management efforts and decisions to be as much successful as several other types of construction projects. Therefore, there is a need to recommend methods to support project management efforts and decisions in achieving expected hospital project development goals. This study developed a cashflow model for monitoring the performance of hospital projects in the construction industry of Hong Kong. With the help of the innovatively combined normalization and percentile methods, the model is developed by using the monthly cashflow dataset of public hospital projects completed in the past 20 years. The model provides relevant alerts to help project managers and decision-makers realize three levels of cashflow performance i.e., green, yellow and red zones. While performance alerts in the green zone are probably fine, performance alerts in the yellow and red zones help in foreseeing existing or potential problems in ongoing hospital projects (i.e., time and/or cost overruns), guiding investigations to unearth any underlying causes of the problems, and providing early warning signals for corrective actions to be taken effectively in time. Theoretically, the study contributes to the knowledge bodies on hospital project success as well as performance modelling. Again, the introduction of the innovatively combined normalization and percentile methods is effective for solving similar research problems.

The findings of the study are relevant for a number of stakeholders and contribute to hospital project performance improvements. The findings would enhance the efforts of government agencies in formulating appropriate policies and legislations for implementing hospital projects. For instance, the Hong Kong government is implementing two 10-year hospital development plans to upgrade, expand and develop several healthcare facilities, amounting to about US$64 billion. As actual hospital projects are monitored with the cashflow model over time, the several monitoring results would build up into a powerful performance database to underlie the formulation of industry-wide policies and legislations to govern the development of hospital projects in Hong Kong. Also, the cashflow model would guide industry practitioners in planning and delivering hospital projects successfully. With sufficient understanding of the performance characteristics of the cashflow model, the practitioners could plan, structure and control work packages in a way that follows the typical cashflow pattern of hospital projects in order to increase the predictability of success. Besides, the hospital cashflow model would serve as a standard reference for researchers to develop different cashflow models for monitoring other unique project types such as railway, school, road, tunnel, pipeline, etc.

Though the study was undertaken successfully, there are some limitations that must be acknowledged. First, the sample size of the dataset is small due to the limited number of projects undertaken across the studied period and the filtering criteria employed. The sample size adequacy has a significant impact on the prediction accuracy of the model. Importantly, the sample size must be increased to a sufficient level to improve the accuracy of predictions. Second, over time, the database underlying the model development will outlive its relevance because of obsolescence. An out-of-date database cannot be significant for predicting cashflow performance at the current time. As such, the underlying database must be continuously refined and updated with only (new) project cashflows of the previous 20 years at any point in time. The normalization method must be followed to update the database and reconstruct the cashflow curves. Third, the model may be best suited for Hong Kong but not for other geographic jurisdictions. Hence, applying the model outside of Hong Kong should be done with caution in respect of the unique nature of hospital projects. Potentially, this model could serve as a good standard to guide the development of similar models in other jurisdictions for conducting comparisons and cross-learning. Fourth, monitoring hospital projects with the model is currently done manually. A digital platform that will allow for easy updates of the underlying database and resulting model as well as the monitoring of new projects will be a great push. Last, the construction industry is gradually embracing artificial intelligence (AI) to support the decision-making process of professionals in the Construction 2.0[1] era. As such, future research should consider incorporating AI into the cashflow model to unlock its best potentials in monitoring, enhancing and controlling hospital projects.

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RETHINKING CONSTRUCTION 4.0 ADOPTION IN NIGERIA: OUTSOURCING AND INSOURCING FOR SUSTAINABILITY IN THE CONSTRUCTION INDUSTRY

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Abstract
The awareness and skills required to implement Construction 4.0, as well as its adoption, are still very low. This study aims at encouraging the insourcing and outsourcing of construction 4.0 technologies for sustainability within the Nigerian construction industry. The sampling technique used for this study was the Purposive sampling technique, Questionnaire was the Primary tool for data collection, while mean, and rank order were used to analyze the data collected. The findings show that the construction-specific construction 4.0 technologies are; LIDAR, and Building Information Modeling(BIM). While the non-construction-specific construction 4.0 technologies are; Big data, Unmanned aerial vehicles, etc. Among the various factors militating against the adoption of Construction 4.0 adoption are; the high cost of acceptance, anddata security issues. The technologies to be insourced are; LIDAR, and BIM, while those to be outsourced are; Big data, Artificial intelligence, etc. Insourcing and outsourcing can help in enhancing sustainability in the construction industry by; helping bridge the skill gap and resolve cyber security issues etc. The study developed a framework for insourcing and outsourcing construction 4.0 within the construction industry and recommends that Construction companies should be adequately sensitized on the benefits of adoptinga new approach to technology adoption.

Keywords
Insourcing, Outsourcing, Construction 4.0 Technology, Sustainability, Adoption
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1. Introduction

Alaloul *et al.* (2018) traced the history of the industrial revolution from the end of the 18th century which was the first industrial revolution that marked the first mechanical loom in 1784;it birthed the water and steam-powered manufacturing facilities. The second industrial revolution which began at the start of the 20th century (first production line, Cincinnati slaughterhouses 1870) birthed electrically powered mass production based on the division of labour. The third industrial revolution started in the 1970s (first programmable controller, Modicon 084, 1969) which used electronics and Information Technology to achieve further automation of manufacturing. While the fourth industrial revolution introduced the use of Cyber-Physical Systems. According to Xu *et al.* (2018); the First industrial revolution was between 1760-1900, with transition periods between 1860-1900, the energy resource was coal and the main technical achievement was the steam engine, the means of transportation was trainand the target industry where textile and steel. The second industrial revolution was between 1900-1960, with a transition period from 1940-1960, the energy resource was oil and electricityand the main technical achievement was the internal combustion engine, the means of transportation were train and car, and the target industries were Metallurgy, Auto, Machine Building. While the third industrial revolution was between 1960-2000, with a transition periodbetween 1980-2000, the energy resources were nuclear energy and natural gas, the main technical achievements were computers and Robots, while the means of transportation were cars and planes, and the target industries were Auto and Chemical. The Fourth industrial revolution was from 2000, with a transition period between 2000-2010, the main energy resource is green energies, and the main technical achievements are; the internet,3D printer, andgenetic engineering, and the transportation means are; electric cars, ultra-fast train, and the target industry are high tech industries.

Industrial revolution 4.0 provides the framework for the Construction industry 4.0 (i.e. Construction 4.0). Construction 4.0 is referred to as the representation of industry 4.0 in construction which makes use of ubiquitous technologies for making decisions in real-time (El Jazzar *et al.*, 2021). Forcael *et al.* (2020) identified the pillars of construction 4.0 to include; the digitalization of the construction industry and the industrialization of construction processes. Various technologies make up construction 4.0 which when adopted can improve the productivity, efficiency, and sustainability of the industry. It also enables smart movement and data revolution needed for the achievement of the united nation's goal of sustainability. But despite the benefits that adopting these technologies provides for the industry, its adoption is still very low in the construction industry compared to other sectors such as manufacturing andbanking (Osusanmi et al,2018). Therefore, this study aims at encouraging the insourcing and outsourcing of construction 4.0 technologies to facilitate the adoption of construction 4.0, and to encourage sustainability in the Nigerian construction industry based on the following objectives; a) To classify the various construction 4.0 technologies into construction-specific and non- construction-specific technologies b) To identify factors militating against the adoption of Construction 4.0 adoption, c)To identify the various construction 4.0 technologies that can be insourced and outsourced d) To identify how Insourcing and outsourcing of construction 4.0 can help facilitate construction 4.0 adoption and enhance sustainability in the construction industry e) To develop a framework for outsourcing and insourcing construction 4.0 technologies in the Nigerian construction industry. Various studies have been carried out on Construction 4.0 and its technologies such as those by; Lekan *et al.* (2021) which examined the disruptive adaptationsof Construction 4.0 and Industry 4.0, Sherratt *et al*. (2020) examined Construction 4.0 and its potential impact on people working in the Construction industry, While Begic and Galic (2021)reviewed Construction 4.0in the context of the BIM premise. But, no study has been carried outon Outsourcing and Insourcing Construction 4.0 technologies for sustainability (especially in Nigeria), hence the need for this study.

2 Theoretical Framework

Agency Theory: it is used to illustrate a delegation of responsibilities from one party to another.It is created when a person (the principal) gives authority to another person (the agent) to act on his behalf (Linder and Foss, 2013); (Nnamseh, *et al.*,2020). This can be related to the study in that, non-construction-specific construction 4.0 technologies that the industry has not adopted can be outsourced outside the construction industry to enhance adoption and sustainability.

Resource-Based Theory: A firm's competitive advantage lies in the resources they possess internally (Nnamseh, *et al.*,2020). Therefore, this theory relates to the study in that construction companies have adopted different construction-specific construction 4.0 technologies, so insourcing within the industry for such competencies and skills will be of great advantage in enhancing adoption and sustainability.

2.1 Construction 4.0 and the Classification of its Technologies

Construction 4.0 is the integration of industry 4.0 into the construction industry (Mansour, *et al.*, 2021). Industrial revolution 4.0 provides the framework for construction 4.0, and some of the technologies which make up industrial revolution 4.0 include; computer-aided design and manufacturing (CAD/CAM), Big data, Additive manufacturing, simulations, and digital automation with sensors (Dalenogare, *et al.*, 2018). According to Kozlovska *et al*. (2021), some of these technologies also make up the Construction 4.0 technologies such as the internet of things, 3D printing, Big data, Augmented, virtual, and mixed reality, robotics, unmanned aerial vehicles, cloud computing, mobiles devices, Artificial intelligence, simulationsof virtual models, sensors and actuators, etc. Furthermore, there are a few of these technologies which are unique to the construction industry such as; Building Information Modeling, 3D Scanner (LIDAR), Modular and Prefabrication technology, etc. Consequently, those technologies which are common to both industry 4.0 and Construction 4.0 can be referred to asNon-Construction specific technologies, while those that are unique to the constructionindustry can be referred to as Construction specific technologies.

2,2Factors Militating against the Adoption of Construction 4.0

Various challenges hinder the adoption of construction 4.0 in the construction industry and various researchers have itemized them in their studies. Among the various factors which militate against the adoption of construction 4.0 are;

a) Low technical know-how (Osusanmi, *et al.*, 2018)
b) Cost acceptance of Technology and Lack of Knowledge **(**Mohd, *et al.*,2019**)**
c) Data security, data protection, and, high implementation costs (Sawhney, *et al.*,2020)
d) Challenges of fluctuating power supply, Dynamics of hackers, and cyber fraud (Lekan, *et al.*,2021)
e) Resistance to change, unclear benefits, and gains (Demirkesen & Tezel, 2021).
f) Technological risk aversion, fragmented nature of the industry (Koc, *et al.*,2020)
g) Hiring skilled people with the required expertise, Heavy lay-offs (Singh & Misra,2021)
h) Lack of awareness and lack of required skills (Adepoju & Aigbavboa,2020).

2.3Outsourcing and Insourcing Construction 4.0 Technologies for Sustainability

Enabling technologies of sustainable development include the Internet of Things, Big data, Cyber-physical systems, Cloud computing, (Ahad, *et al.*,2020), etc. These technologies make up the Construction 4.0 technologies. Adepoju and Aigbavboa (2020) observed that some of these technologies are already in use such as Building Information Modeling (BIM), and Prefabrication, while Robotics and Green building has low implementation. Furthermore, there is a willingness by construction professionals to adopt construction 4.0 technologies, hence the need to insource where the technology is construction specific and being used within the industry because of the prevalence of knowledge/know-how among construction professionals. And outsource those technologies that aren't construction specific since their knowledge can be gotten outside the industry.

Outsourcing is the engagement of the services of specialized service providers to deliver predefined services(Meyer,2022). It gives a chance for specific skills to be gotten, lowers cost and management of risk (Dinu, 2015). Furthermore, Amusan *et al. (*2022) identified the areas of application of outsourcing concepts in Construction firms to include; Human resources, Training of human resources and the management of construction sites. While Insourcing is the production of a product or the performance of services by the in-house resource (Meyer,2022). It helps in cost reduction, dealing with quality, and control issues (Luhtala, 2021).Collectively, both outsourcing and insourcing can help with the challenges of cyber security threats, resources optimization, cost reduction, and capacity issues (both short and long-term goals). Furthermore, they both help in process expansion, enhancement, and economization, aswell as increasing revenue(Taveras,2015). The technologies that makeup construction 4.0 are both specific and non-specific to the construction industry, therefore if the adoption rate must be enhanced there is a need for an in-house collaboration between construction companies and collaboration between construction companies and other non-construction companies.

3.Research Methodology

The study adopted the use of a survey research design**,** the study surveyed three constructionsites and two works departments of a tertiary institution in Ota, Ogun state. A Population of 57 respondents comprised of professionals such as Architects, Builders, Quantity surveyors, CivilEngineers, Mechanical and Electrical Engineers, etc. Both Primary and, Secondary methods of data collection were used for this study. A quantitative approach was adopted using structured questionnaires (which was the primary data collection tool), Published articles, Journals, textbooks, etc.made up the secondary sources, of the data collection instrument. The sampling technique usedwas the purposive sampling technique because respondents had the requisite experience and were also the primary actors (who could tell the actual state of knowledge). A sample size of 50 was used for the study, which was determined through the use of the taro Yamane formula

($n = N/ 1+ N(e)^2$), Where N is the population of the study, and e is the sampling error. The datawere analyzed bymean score, rank order, frequency, tabulation, and percentages. Also, a Likertscale of 1-5 was used for this study, where 1 is Strongly Disagree, 2 is Disagree, 3 is Undecided,4 is Agree, 5 is Strongly Agree)

4. Results

4. 1 Profession of respondent

Table 1 Profession of respondent

S/N	PROFESSION	NUMBER OF RESPONDENTS	PERCENTAGE
1	Architect	15	30%
2	Builder	9	18%
3	Structural Engineer	4	8%
4	Quantity Surveyor	10	20%
5	Mechanical Engineer	5	10%
6	Electrical Engineer	7	14%
	TOTAL	**50**	**100**

Source: Research Survey (2023)

From Table 1, it can be seen that the profession of the respondents are; Architects with a percentage of 30%, Quantity surveyors with a percentage of 20%, Builders with a percentage of 18%, Electrical engineers with a percentage of 14%, Mechanical engineers with a percentageof 10% and Structural engineers with a percentage of 8%

4.2. Years of experience of respondents

Table 2 Years of the Respondents

S/N	YEARS OF EXPERIENCE	NUMBER OF RESPONDENTS	PERCENTAGE
1	2-10 YEARS	10	20%
2	10-20 Years	35	70%
3	20-35 Years	5	10%
	TOTAL	**50**	**100**

Source: Research Survey (2023)

From Table 2, it can be observed that respondents are mainly between 10-20 years with a percentage of 70%, those between 2-10 years with a percentage of 20%, and those between 20-35 years with a percentage of 10%.

4. 3 Construction-Specific and Non-Construction-Specific Construction 4.0 Technologies

Table 3 Construction-Specific and Non-Construction-Specific Construction 4.0 Technologies

S/N	Construction-Specific	MEAN SCORE	RANK
1	3D Scanner(LIDAR)	3.46	3
2	Modularization and Prefabrication	4.52	2
3	Building Information Modeling(BIM)	4.60	1
S/N	**Non-construction-specific technologies.**	**MEAN SCORE**	**RANK**
1	Internet of things	4.8	1
2	3D printing	4.7	2
3	Big data	4.26	3
4	Mobiles devices	4.22	4
5	Unmanned aerial vehicles	4.22	4

Source: Research Survey (2023)

Table 3 shows that respondents agree that the Construction specific technologies are; Building Information Modeling(BIM) with a mean of 4.60, Modularization and Prefabrication with a mean of 4.52, and 3D Scanner(LIDAR) with a mean of 3.46 While the Non-construction specific technologies are; Internet of things with a mean of 4.8, 3D printing with a mean of 4.7,Big data with a mean of 4.26, Mobiles devices mean of 4.22, and Unmanned aerial vehicles with a mean score of 4.22.

4. 4 Factors militating against the Adoption of Construction 4.0

Table 4 Factors militating against the Adoption of Construction 4.0

S/N	Factors militating against the adoption of Construction 4.0	MEAN SCORE	RANK
1	Lack of knowledge and Low technical know-how	4.38	2
2	Lack of Awareness	3.26	5
3	Cost of technology acceptance andhigh cost of Implementation.	4.4	1
4	Resistance to change and Heavy layOff	3.58	4
5	Data security, Protection issues	4.04	3

Source: Research Survey (2023)

Table 4 shows that respondents agree that the factors militating against the adoption of construction 4.0 adoption are; Cost of technology acceptance and the high cost of Implementation with a mean of 4.4, Lack of knowledge and Low technical know-how with a mean of 4.38, Data security, Protection issues with a mean of 4.04, Resistance to change and Heavy lay off with a mean of 3.58, and Lack of Awareness with a mean of 3.26.

4.5 Construction 4.0 Technologies to be Insourced and Outsourced

Table 5 Construction 4.0 Technologies to be Insourced and Outsourced

S/N	Construction 4.0 Technology	MEAN SCORE	RANK
1	**Insourced Technologies**		
	LIDAR	3.66	3
	Building Information Modeling	4.50	1
	Modular and Prefabrication	4.46	2
2	**Outsourced Technologies**		
	Internet of things	3.68	5
	Big data	4.48	1
	Augmented, Virtual, Mixed Reality	4.26	3
	Cloud computing	4.18	4
	Artificial intelligence	4.34	2

Source: Research Survey (2023)

Table 5 shows that respondents agree that the various technologies to be insourced are; Building Information Modeling with a mean of 4.50, Modularization and Prefabrication technology witha mean of 4.46, and LIDAR with a mean of 3.66.

4. 6 Benefits of Insourcing and Outsourcing Construction 4.0 Technologies

Table 4.6 Benefits of Insourcing and Outsourcing Construction 4.0 Technologies

S/N	Benefits of Insourcing and Outsourcing of Construction 4.0 technologies.	MEAN SCORE	RANK
1	Increase in revenue and resource optimization.	3.26	5
2	Dealing with capacity issues (i.e. bridging the skill gap and technical know-how)	4.50	1
3	Reduction in the Cost associated withthe technology adoption.	4.38	2
4	Expansion, enhancement, and economization of Process.	3.46	4
5	Resolving Cyber security threats.	4.22	3

Source: Research Survey (2023)

Table 6 shows that respondents agree that Insourcing and Outsourcing of Construction 4.0 technologies can facilitate construction 4.0 adoption and enhance sustainability in the construction industry by; Dealing with capacity issues with a mean of 4.50, Reduction in the cost associated with the technology adoption with a mean of 4.38, Resolving cyber security threats with a mean of 4.22, Expansion, enhancement, and economization of Process with a mean of 3.46, Increase in revenue and resource optimization with a mean of 3.26.

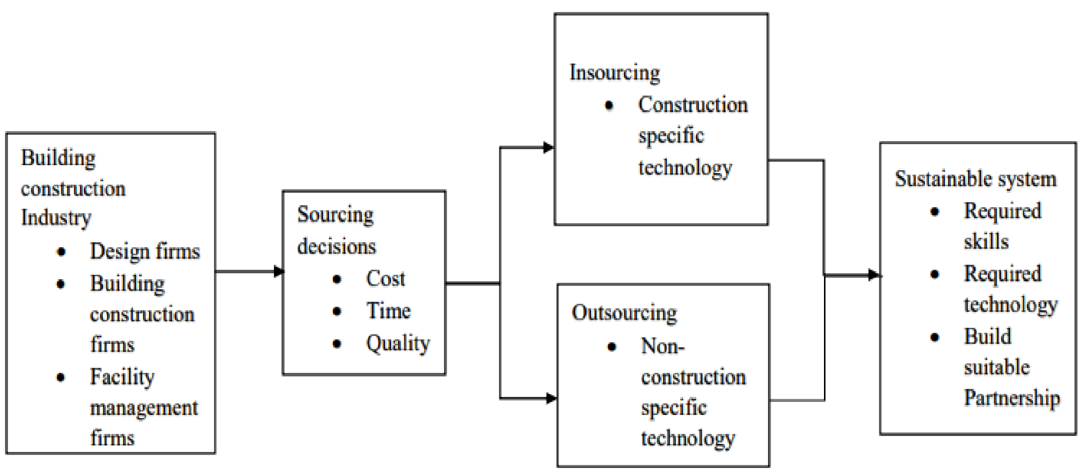

Fig 1 Proposed Framework for outsourcing and insourcing Construction 4.0 Technologies

The need to insource and outsource Construction 4.0 technologies in the Building Construction industry should be holistic, that is should involve companies in all phases of Construction such asdesign firms, construction firms, and facility management firms. This will help enable sourcing decisions.

Sourcing decisions for Construction 4.0 should be focused on the three parameters of project success such as cost (which includes cost acceptance of technology, cost of implementation), time(which includes the time it takes to acquire the relevant technology and skills), and quality (the quality of output desired). This will help to determine whether to insource or outsource.

To decide whether to Insource and Outsource Construction 4.0 technologies, Constructioncompanies should decide which construction 4.0 technologies to insource and outsource (i.e. Construction specific technologies and Non-Construction specific technologies) as this will help the industry in acquiring the relevant skill and technologies, and in the long-run in achieving a project goal of cost and time reduction, and quality improvement. This will help enable a sustainable system.
To achieve a sustainable system, the right technology, the right skills, and suitable partnershipshould be built.

4. Discussion

The various construction 4.0 technologies can be classified into construction-specific such as BIM, Modular and Prefabrication technology, and LIDAR, while the non-construction-specifictechnologies are; Internet of things, 3D printing, Big data, mobile devices, and Unmanned aerialvehicles. This agrees with Ngowi *et al.* (2005) which stated that one form of industrialization (i.e. of construction) is Prefabrication, which is the industrial manufacture of building components off or near the site. While Doan *et al.* (2019) stated that BIM is a fusion of CAD, information management, and collaboration, which spans various building delivery workflowssuch as architectural, electrical structural, etc. Halili, (2019) in his study identified the various industrial revolution technologies such as; Artificial intelligence, the Internet of things, and bigdata relevant for students in the workplace. While Lazim *et al.* (2020) in their study adopted theuse of these technologies such as the Internet of Things, autonomous robot, big data analytics, and artificial intelligence in the Agricultural sector.

The Factors militating against the adoption of Construction 4.0 are; Lack of knowledge and Low technical know-how, Lack of Awareness, cost of technology acceptance and high cost of implementation, resistance to change and heavy layoff, data security, and Protection issues. This agrees with Zhi *et al.* (2022). which identified lack of technical skill and knowledge, lackof manpower, lack of awareness, etc. as major barriers to the adoption of Industrial revolution in the Malaysian construction industry. Ibrahim et al. (2022) identified the hindrances to the adoption of Industrial revolution 4.0 by construction consultants are; the cost of adopting the technologies, cost of adopting the technologies.

The various construction 4.0 technologies that can be insourced are; LIDAR, Building Information Modeling, and Modular and Prefabrication. This agrees with Chang, *et al.* (2018) which state that for building prefabrication to succeed in china, there was a need for job site training and apprenticeship. While those to be outsourced are; the Internet of things, Big data, Augmented, Virtual, Mixed Reality, Cloud computing, and Artificial intelligence. This agrees with Chang-Richards *et al.* (2022). which state that there is a need to outsource technical skillssuch as machine learning, deep learning, etc. as a stand-alone disciplinary approach will not behelpful in creating the necessary talent pool needed in the industry. The study emphasized the need for a balance between depending on a third party and incubating home-grown solutions by recruiting/upskilling.

The Benefits of Insourcing and Outsourcing of Construction 4.0 technologies are; Increase in revenue and resource optimization, increase in revenue and resource optimization, dealing withcapacity issues, Reduction in the Cost associated with the technology adoption, expansion, enhancement, and economization of process, and resolving cyber security threats. This agrees with Chang-Richards *et al*. (2022) which state that collaboration, partnership, third-party engagement, recruiting, and up-skilling can help change the culture and mindset of employees at all levels, develop technical skills, and provision of critical talent capabilities in the construction industry and help to facilitate successful technology adoption/implementation.

5. Conclusions

The advent of the Industrial revolution provided the framework for Construction4.0, hence thetechnologies that make up Construction 4.0 are a mixture of both Industrial revolution technologies and those of the construction industry such as Modularization and Prefabrication technology, Building Information Modeling (which are both Construction-specific technologies), while technologies such as The internet of things, Cloud Computing, Artificial Intelligence are the Non-Construction specific technologies. The adoption of these technologiesin the Construction industry has been hindered by several factors among which include; Lack of knowledge and Low technical know-how, Lack of Awareness, cost of technology acceptance and high cost of implementation, resistance to change, and heavy layoff, data security, and Protection issues. Therefore, the need to outsource some of those technologies which are not unique to the construction industry such as the internet of things, Artificial intelligence, and insource those technologies which are unique to the construction industry such as BIM, Prefabrication technology, to facilitate the quick adoption of these technologies and enhance sustainability in the Construction industry. A framework was developed in the study that could in the quick adoption of Construction 4.0 technologies in the Nigerian construction industry. This study is limited to the Construction industry (especially in Nigeria) experiencing a slow adoption rate of technology. To this end, the study recommends that Construction companies should collaborate within themselves and with othernon-construction companies to hasten the adoption of these construction 4.0 technologies, Government should provide a regulatory framework for insourcing and outsourcing activities between companies and within the country, the right professionals with the requisite skill shouldbe placed in the right position, so as encourage the insourcing strategy, Construction companiesand Professionals should be adequately sensitized on the benefits of adopting a new approach to technology adoption, Training and development should be encouraged by construction companies, in order to acquire and sharpen skills. Further studies can be carried out in other Construction industries around the world with other analytical methods. This study contributes to knowledge in that it will help encourage a faster and better way to hasten the adoption of Construction 4.0 and provide a quick way in which Construction companies can bridge the skill and technology gap associated with Construction 4.0 through outsourcing and insourcing. Thereby, fostering innovation, building resilient infrastructure, and enabling sustainable development

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Industry 4.0 Awareness on Built Environment Professionals: A Study on the Current State of Knowledge and Adoption in UAE

Maged El-Hawary[1], Ameer Buhari[2]

Abstract

The Fourth Industrial Revolution, also known as Industry 4.0, has brought a significant change in the way industries operate worldwide. This technological revolution has transformed traditional manufacturing processes and has ushered in a new era of automation, artificial intelligence, big data, and the Internet of Things (IoT). These innovations have enabled a higher level of connectivity and efficiency across industries, including the built environment sector. This study aims to assess the level of Industry 4.0 awareness and adoption among Built Environment Professionals (BEPs). BEPs are a group of professionals who are responsible for the planning, design, construction, and maintenance of the built environment, including architects, engineers, builders, and facility managers. This research will employ a mixed-method approach, including a survey and interviews, to gather data on BEPs' current understanding of Industry 4.0 technologies and how they are integrating them into their work processes. The findings of this study will help to identify the gaps in the current knowledge and skills of BEPs with regards to Industry 4.0 technologies. The research will also explore the challenges faced by BEPs in adopting Industry 4.0 technologies and the potential benefits that can be gained from their integration. The results of this study can be used to inform the development of training programs and professional development opportunities for BEPs to enhance their knowledge and skills in Industry 4.0 technologies, thereby improving the efficiency and effectiveness of the built environment sector.

Thus, to pursue the aim of this study, the data and views were collected from more than 200 professionals and the Interviews were conducted with the senior professionals for further analysis. At the end of the study, the findings revealed that there is serious concern of awareness on important technologies like CPS, BIM, AI, and Virtual reality, which are going to play an important role in the Built Environment Industry soon. Moreover, it was observed that, both the survey participants, Interviewees and their respective Organizations were having less usage on the important technologies like Building Information Modelling, Cyber Physical systems at their organization.

Keywords: Industry 4.0, Cyber-Physical System (CPS), Information and Communication Technology (ICT), Physical-Digital-Physical Loop (PDP), Built Environment Professionals (BEPs)

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1.0. Introduction:

The term "Industry 4.0" was first coined by Germany in 2011 as a part of the strategy to improve the high-tech Industries in Germany through the adoption of ICT. According to the Author Jennifer, the Fourth Industrial Revolution is an umbrella term which encompasses all the mega trends happening due to the Cyber-Physical System (CPS) and ICT(Castañeda-Navarrete et al., 2020). When the CPS and ICT application is used in the construction process, it becomes Construction 4.0; subsequently, when it is used in the Manufacturing Industry, it becomes Industry 4.0.Therefore the primary foundation of the Industry 4.0 is ICT and CPS(Gürdür *et al.*, 2016). The cyber link between the digital world and the physical world will be seamlessly done both ways in a Physical-Digital-Physical loop(Cotteleer, 2017). The Cyber-Physical link refers to the network connections between humans, machines, products, and objects through ICT systems.

CPS can create a replica of the building in the physical world, called the "Digital twin", through technologies like "Building Information Modelling". The Digital Twin of the building can serve as a medium to observe, visualize, analyze, and control the physical structure or twin in the real world (Shelden, 2018). As the digital model is already available, these technologies can also be adapted to support the Facilities Management function. For example, RFID can incorporate barcodes, which can be used with Augmented Reality and BIM to locate the equipment and facilitate Maintenance quickly. Therefore, the Digital technologies such as BIM and Augmented Virtual reality is expected to play a significant role in transferring existing building asset from the physical world to the digital world. In contrast, physical technologies like 3D printing, Industrialized construction will do the same in moving the digital model to the physical world in the case of new building design and execution. The physical and digital worlds will be linked through the Internet of Things, Actuators, sensors, and Networks. Therefore, Fourth Industrial Revolution will expect future BEPs to perform in a globally networked environment between the physical and virtual worlds. Hence, in the built environment sector, Industry 4.0 has the potential to revolutionize the way buildings are designed, constructed, and managed, improving productivity, efficiency, and sustainability. However, the successful implementation of Industry 4.0 technologies in the built environment sector requires professionals who possess the necessary skills and knowledge. Even though, there were significant number of studies on the awareness of Industry 4.0 and usage on other professions, there are only limited study available on the BEP professionals. Thus, understanding the level of awareness and adoption of Industry 4.0 among built environment professionals is crucial to meet the industry's evolving needs.

This research aims to investigate the current state of Industry 4.0 awareness and adoption among built environment professionals in the United Arab Emirates (UAE) and to identify the skills and knowledge required to facilitate the transition towards Industry 4.0. The findings of this study will be of significant value to professionals, policymakers, and academic institutions involved in the built environment sector, and contribute to the sector's overall readiness to embrace Industry 4.0.

2.0 Literature Review

2.1 UAE Built Environment: Adapting to Rapid Digital and Green Changes

UAE has implemented key policies and strategies to ensure the nation remains at the forefront of modern technologies and trends. Change is the Inherent part of any crisis, whereas rapid change is the reality of the Covid-19 crisis, especially for the building and construction Industry. The Covid Crisis has accelerated this change, and digital technology has become the new normal in any Industry, including building construction and operation(Ulrik Branner and Thomas Goubau, 2020).

Post the Covid-19 crisis, UAE Leadership realized that the economic models with traditional policies in boosting only the economy, job growth and financial returns alone in a narrow-minded manner are not sufficient. To identify the future trends, the Centennial Lab at the UAE Prime Minister's office, along with the United Nations and Horizon Group, published "Future Possibilities Report 2020" on the 75th Anniversary of the United Nations. The report identified six transformational trends that would have a likely impact of 5 to 10 years on the country.

The Below drawing figure the six transformational trends and their impact on the Built Environment.

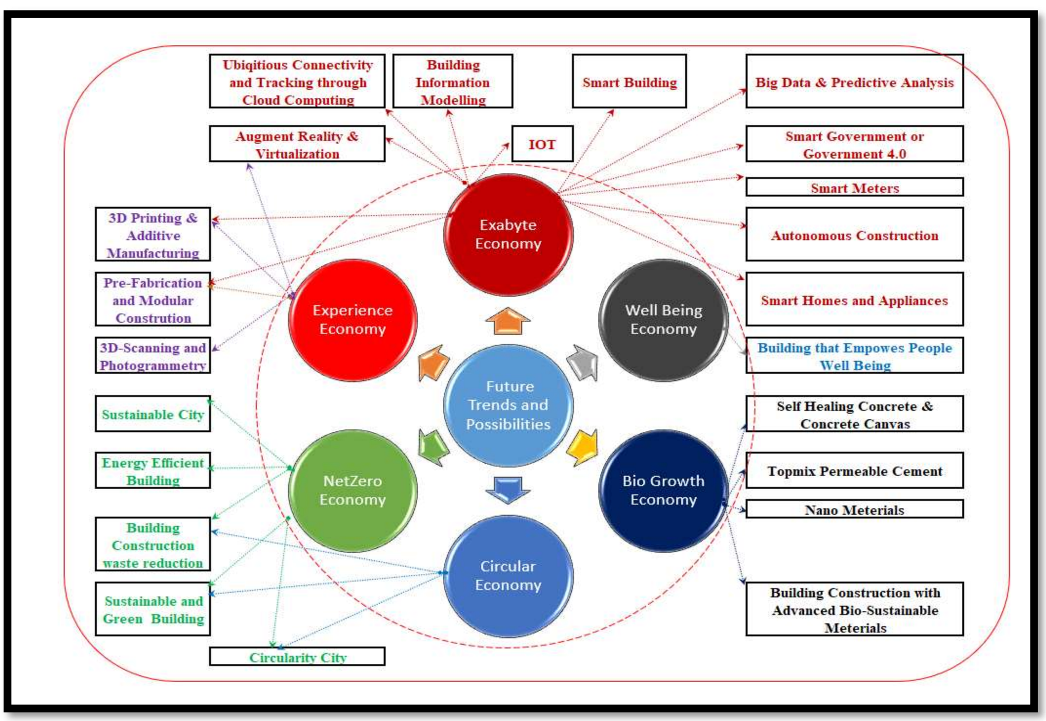

Figure 1. Six Transformational Trends Identified by "Future Possibilities Report" (Authors' Representation)

These transformational trends are expected to have a massive change in the Built Environment. A digital ecosystem is a group of products, people or enterprises working in an interdependent manner on a common digitized standard platform for their typical gain or mutual interest (Panetta, 2016). Therefore, in a virtually focused future economy of UAE, the entire life cycle of the building construction and operation will be autonomous in the digital ecosystem. The Construction process is expected to change from a highly fragmented project-based approach based on unique customer requirements to a product-based system with standardization and flexibility. The construction and Facility Management of the building will be autonomous with less human intervention, and the human workforce will be required in the future only for robot maintenance and project supervision. The project will be supervised and collaborated more digitally only to oversee the project and to maintain the robots. Digitalization and technological advancement will push the industry players to shift towards off-site construction, Prefabrication, and Additive Manufacturing. The factories will mass produce and supply large quantities of Customized modules in less than a decade. There will be a new business model created out of a large amount of data that exist in the virtual world. The Digitized building objects and the sensors' data will allow companies to generate new revenues and services. The Business model of stand-alone contractors, sub-contractors without highly specialized skills and Operation & Maintenance companies will be at risk of disruption, as their work is now automated. Those companies that cannot embrace digital or leverage digital technologies will soon be out of business in the UAE.

The Built Environment accounts for 70% of Energy consumption in this region compared to the global average of 40%(Tabet Afoul et al., 2018). The per capita electricity consumption in UAE is also considered one of the highest in the world. This pushes the UAE Government to work towards Green economic models such as Net Zero Economy, Circular Economy, Well Being Economy, and Bio-Growth Economy. UAE Ministry of Climate Change, in partnership with "The Global Green Growth Institute", has developed a road map ", National Climate Change plan of UAE 2017-2050", to strengthen the national action plans for mitigating climate change(Government, 2017). The UAE Strategy exemplified by the UN Sustainability targets will compel the Built Environment Industry players to factor sustainability in their value chains, such as building materials, construction process and design. The industry players will adopt Innovative technologies and new sustainable materials to reduce the environmental impact. Design and Engineering Firms will move from traditional design practices to "Nature Positive Built Environment Design", where the entire ecosystem will be placed at the Centre of the design rather than placing humans as the only focus of the design(Akanksha Khatri and Dominic Waughray, 2020). The Built Environment sector will see the increased deployment of resource engineers, circular Economy specialists and simulation experts to produce the asset with the most negligible environmental impact over their Entire Building Life Cycle.

The building materials will be taxed based on their origin and recyclability. The industry will prefer locally sourced or renewable bio-engineered materials to make the building more durable and sustainable. Most of the buildings will be 3D printed out of new materials, as this will minimize construction waste. UAE plans to have 25% of Dubai's buildings printed by 3D printing technology by 2030(Rajan et al., 2018).

Industry players with extensive knowledge of Sustainable practices and the latest technology only can survive and thrive in the green future, as sustainability will become a prime criterion for making a choice.

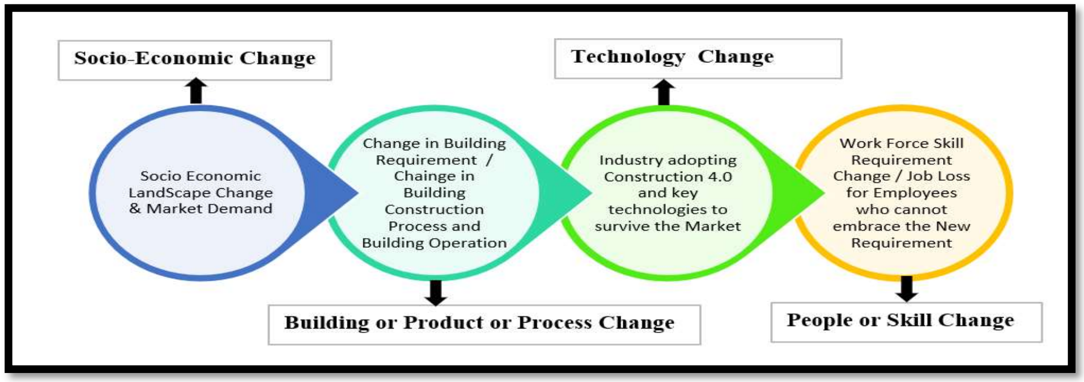

Figure 2. Work Force Skill Change due to Economy & Industry (Source: Authors' Representation)

Based on the above discussion, the buildings are changing from "grey and dumb" to "Green and smart". Those players who cannot think smart and green cannot create superior value for the end-users. The industry players who cannot adapt will completely disappear from the market in a few years. According to the Mckinsey report, construction is identified as one of the top six sectors, where 60% of the Jobs have the potential to be automated in the Middle East(Aus dem Moore, Chandran and Schubert, 2018). Many occupations related to the Built Environment are threatened by technology, Data, and computerization(Thompson and Waller, 2017). As the socio-economy of the UAE changes to a Digital, Industrial, and sustainable economy, the industry and its workforce have no other option to change, as depicted below.

Based on the discussion, it was clear that the Building Industry is fast changing due to the Innovative strategies and policies of the UAE government. The UAE government's innovative strategies and policies have led to a fast-changing Building Industry. To keep up with the industry's changes, Built Environment professionals such as Architects, Engineers, and technicians need to be aware of digital, physical, and sustainable technologies. They must also develop leadership skills and a mindset for lifelong learning, growth, and resilience to remain relevant in the industry. Failure to do so may lead to the displacement of human workers by disruptive intelligent machines.

3.0 Methodology:

To critically examine the industry 4.0 technology awareness and its usage, the survey and the Interview was conducted through an with BEPs. The primary target of the survey participants was the professionals actively involved in Building Construction and

Operations. The main goal of that survey was to collect feedback from the professionals on the awareness and the usage of Industry 4.0 Technologies. The survey was distributed to the professionals through social media, linked in and through what's app. The total number of responses received was 203. After the survey, the Interview was conducted with the Consultants and senior professionals shown below (Table-1) to understand better and analyze the survey data collected.

The heterogeneousness of the survey data is reinforced by the fact the survey response was from different hierarchy level with staff (45%, 92 replies), Managers (26%, 53 responses), Senior Managers (10%, 20 responses), Directors/ Corporate executives (8%, 16 responses) and Others (10.89%, 22 responses). The response came from a broad level of Industry professionals working across the Industries of Real Estate Development (Pre-construction), Construction and Operations. The Survey response came from a comprehensive group of Industry professionals working across the Industries of Real Estate Development (Pre-construction), Construction and Operations.

Sr.No	Role	Experience (Years)	Industry type	Expertise	Interview Date and Time
1	Managing Director (Interviewee-1)	16	Developer/ Mall Management	Mall Management / Real Estate Developer	16th June 2021, 6 till 7 PM (1 Hour)
2	Consultant (Interviewee-2)	16	Critical Facilities Management / Data Centre / Consultancy	Critical Facilities / Data Center / Consultancy / ICT Resilience Expert	18th June 2021,8 till 9 AM (1 Hour)
3	Senior Manager (Interviewee-3)	15	IOT / Industry 4.0 / Digital Transformation	Artificial Intelligence of Things / Cloud / Mobility / Industry 4.0 / Digital Transformation / Connected Living	19th June 2021, 12.30 till 1.30 PM (1 Hour)
4	Senior Manager (Interviewee-4)	15	Digital Transformation / IOT Solutions	IIOT / Automation / End-End Digital Transformation	02nd July 2021, 5 till 05.40 PM (40 minutes)
5	Senior Manager (Interviewee-5)	20	Construction / Property and Asset Management	Solution Architect - M-Serivces / ERP / IOT	03rd July 2021, 5 till 5.30 PM (30 minutes)

Table 1-Interview Details (Qualitative Analysis)

The Interviewee participants (Table 1) were carefully handpicked with more than 15 years of domain experience in Building Construction and Maintenance, Digital Transformation, and Industry 4.0 Technologies. The survey participants comprised only 10% having less than a year of experience, 27% having more than 15 years and 28% having 9 to 15 years. Hence, most survey participants had enough experience to provide legitimate survey responses on this industry.

4.0 Survey & Interview Data Results and Discussion

Participants in the survey were presented with a list of Industry 4.0 technologies and asked to rate their opinions on two aspects using a scale of 1 to 5:

1. Participant Awareness on the listed Industry 4.0 technologies
2. Extend of Usage in their Organization (Listed Technology Usage)

The list of Industry 4.0 technologies was obtained from the "Industry 4.0 Opportunities, behind the Challenge" report by the United Nations Industrial Development Organization(Dr. Mirjana Stankovic *et al.*, 2017).The survey response was analyzed and grouped under three categories of "Low, High and Average" Awareness. As shown in the survey response table below (Table-2), the top three technologies having awareness among professionals are Mobile Technologies, RFID, and the Internet of things. The professionals do not understand Cyber-Physical Systems, Augmented reality, 3D Printing and Building Information Modelling in the respective Order. There is the slightest awareness of Cyber-physical Systems, with only 25% of the respondent choosing the "High awareness" option.

	LOW	AVERAGE	HIGH	
Technology Awarness	1 & 2	3	4 & 5	TOTAL
Mobile and Wearable Technologies	13%	21%	65%	100%
RFID and Barcoding Technology	19%	28%	53%	100%
Internet of things (IOT) , Sensors and Actuator Technology	20%	25%	55%	100%
Artificial Intelligence and Machine Learning	25%	28%	48%	100%
Robotics and Automation	25%	29%	46%	100%
Big Data, Predictive Analytics and Cloud Computing	26%	26%	48%	100%
Industrialized Construction	29%	35%	36%	100%
Drones and Un-Manned Aerial Vehicle System	33%	28%	39%	100%
Building Information Modelling (BIM)	29%	37%	33%	100%
3D Printing and Additive Manufacturing	35%	31%	34%	100%
Augmented and Virtual Reality Technologies	34%	31%	35%	100%
Cyber Physical System(CPS)	45%	30%	25%	100%

Table 2- Table showing the Survey Response on Industry 4.0 Technologies Awareness

The below table (Table-3) shows the "Extend of Usage" response summarized in three categories "High, Average and Low". A comparison between the current usage (derived from survey responses) with the "Expected usage" derived from the literature review of "The Construction 4.0: Roadmap to the Shaping the Future(El Jazzar *et al.*)" is made and shown below.

	LOW	AVERAGE	HIGH		Expected Usage			
Extend of Usage in your Organization (Current Usage)	1 & 2	3	4 & 5	TOTAL	Planning	Design	Construction	Facility Management
Mobile and Wearable Technologies	23%	20%	58%	100%	LOW	LOW	MEDIUM	VERY HIGH
RFID and Barcoding Technology	28%	24%	47%	100%	LOW	LOW	MEDIUM	VERY HIGH
Internet of things (IOT) , Sensors and Actuator Technology	31%	27%	42%	100%	LOW	LOW	MEDIUM	VERY HIGH
Artificial Intelligence and Machine Learning	36%	27%	37%	100%	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH
Robotics and Automation	39%	28%	33%	100%	LOW	MEDIUM	HIGH	HIGH
Big Data, Predictive Analytics and Cloud Computing	46%	21%	34%	100%	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH
Industrialized Construction	46%	24%	30%	100%	MEDIUM	MEDIUM	VERY HIGH	LOW
Drones and Un-Manned Aerial Vehicle System	50%	22%	28%	100%	LOW	MEDIUM	HIGH	HIGH
Building Information Modelling (BIM)	49%	27%	24%	100%	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH
3D Printing and Additive Manufacturing	49%	28%	23%	100%	HIGH	HIGH	VERY HIGH	LOW
Augmented and Virtual Reality Technologies	59%	16%	25%	100%	HIGH	HIGH	MEDIUM	MEDIUM
Cyber Physical System(CPS)	54%	26%	20%	100%	LOW	LOW	VERY HIGH	VERY HIGH
					Planning	Design	Construction	Facility Management

Table 3 -Table Showing the Survey Response on "Low, Average and High" Usage

Based on both the tables (Table-2 and 3), the First three technologies are same for the "Awareness and extend of usage", which indicates that there is already a heavy penetration of these three technologies (Mobile, RFID and IoT) in the Built Environment Industry Construction and Operation. 3D Printing and Additive Manufacturing come last, with only 11 (only 8%) respondents stating that their organization has high usage. Even though Dubai has an ambitious strategy of having at least 25% of its buildings 3D Printed by 2030 (Dubai 3D Printing 2030), the market penetration of 3D Printed technology, according to the table below, is less. This indicates that there will be a supply-side issue when there is a requirement for 3D-printed buildings in this region to meet the ambitious government target.

From the above comparison table, it is observed that the cyber-physical system has got minor usage in this region. Even the Interviewee participants, who are in the technology space of the Built Environment, are not aware of CPS much; instead, they understand it in terms of digitalization. Results inferences that the industry is not well advanced towards industry 4.0, as the cyber-physical system is the core of the Fourth Industrial Revolution. Less than 50% of the organization are using BIM, Big Data and Artificial Intelligence. This is alarming, as there will be a high reliance on these technologies for the entire life cycle of the building Construction and Operation in the future. Based on the survey result, the question was posed to the Interviewees about why Mobile Technologies, RFID and IoT are in the top three spots on awareness, impact, and usage when compared to other technologies like BIM, 3D Printing and Cyber-physical systems.

The Interviewee Participant responded that it is because of the awareness, cost, and people's resistance to change. In the case of Mobile or wearable technologies or RFID or IoT, the technology is intuitive to your brain, as people can touch and feel comfortable using the applications with limited training. Moreover, mobile or wearables or RFID technologies were a luxury in the past decades. Now, they have become a necessity due to their wide adaptation among the masses due to their cheap cost.

The cost of implementing or adapting Mobile Technology or application is easy, as the platform or hardware or wireless infrastructure to adopt it is already available. But in the case of BIM or 3D Printing or Cyber-physical systems, the awareness is less, and the technology is not widely adopted till now. Moreover, the cost of these technologies is high and requires skilled personnel or specialized training to implement this on the projects. The price is high and requires much change and training, so there is resistance to change. Therefore, the technology is adopted where there is a mandatory requirement for the project.

5.0 Theoretical and Practical Implementation:

The results of the study indicate that the built environment industry in the region is not well advanced towards industry 4.0, as less than 50% of the organizations are using BIM, Big Data, and Artificial Intelligence. This presents an opportunity for researchers and academics to further explore the potential benefits of these technologies in the industry and identify ways to increase their adoption. One theoretical implementation could involve developing a training and education program for industry professionals on the benefits of these technologies and how to effectively implement them in projects. This program could include courses on BIM, data analytics, and AI, as well as hands-on training sessions with industry-specific software and hardware. The program could be offered in partnership with industry associations or professional organizations to ensure maximum exposure and adoption. Another theoretical implementation could involve developing a framework for the integration of cyber-physical systems in the built environment. This framework could include guidelines for selecting and implementing appropriate CPS technologies, as well as a roadmap for their adoption and integration into the construction and operation of buildings. The framework could be developed in collaboration with industry experts and organizations to ensure it is practical and applicable to real-world projects.

One practical implementation could involve partnering with local governments and organizations to incentivize the adoption of these technologies in building projects. This could include offering tax breaks or other financial incentives to companies that incorporate BIM, Big Data, and AI into their projects. It could also involve providing funding or resources to support the training and education of industry professionals in these technologies. Another practical implementation could involve developing pilot projects to showcase the benefits of these technologies in real-world scenarios. These projects could be developed in collaboration with industry partners and could include the integration of BIM, data analytics, and AI in building design, construction, and operation. The results of these pilot projects could be shared with industry professionals to demonstrate the potential benefits of these technologies and encourage their wider adoption.

Overall, the study highlights the need for increased awareness and adoption of advanced technologies in the built environment industry. Furthermore, it may be beneficial to conduct more research and development to make CPS more accessible and affordable for the industry. This could involve creating open-source CPS platforms that can be easily customized and integrated into existing building management systems. In summary, promoting awareness and education, incentivizing adoption, and investing in research and development are practical steps that can be taken to increase the adoption of CPS in the built environment industry. By doing so, the industry can take a significant step towards embracing Industry 4.0 and reaping the benefits that come with it.

6.0 Limitations and Re-commendation

One limitation of the study is that it was limited to a specific region, the UAE, and therefore may not be generalizable to other regions or countries. Additionally, the sample size of the survey was relatively small, and the study relied on self-reported data, which may be subject to response bias. Finally, the study focused primarily on the awareness and usage of specific technologies and did not explore in-depth the reasons behind the lack of adoption or awareness, nor did it examine the potential challenges or barriers to implementing these technologies in the UAE Building Industry.

Based on the findings of this study, there are several recommendations for concerned stakeholders in the UAE Building Industry. Firstly, there is a need to invest in training programs and workshops to increase awareness and knowledge of Industry 4.0 technologies, such as CPS, BIM, AI, and Virtual Reality. These programs should be accessible and affordable to professionals and companies of all sizes.

Secondly, the concerned stakeholders should collaborate with academic institutions and research centers to foster innovation and research in the field of Industry 4.0. This collaboration will lead to the development of new technologies and solutions that are tailored to the needs of the UAE Building Industry.

Thirdly, there is a need for government support in promoting the adoption of Industry 4.0 technologies through the provision of incentives and subsidies. This will encourage companies to invest in these technologies and stay competitive in the market.

Finally, concerned stakeholders should also promote knowledge-sharing platforms and forums to encourage professionals to exchange ideas and experiences on the implementation of Industry 4.0 technologies in the Built Environment. This will lead to a more informed and collaborative industry, which will be better equipped to face the challenges and opportunities of the Fourth Industrial Revolution.

7.0 Conclusion:

After the study, it was found that there is a concerning lack of awareness and usage of important technologies, such as Building Information Modelling, Cyber-Physical systems, Industrialized construction, and 3D Printing, in the UAE Building Industry. Even experts in technology in the Built Environment have limited knowledge of CPS and understand it more in terms of digitalization. This study emphasizes the urgent need for the adoption of CPS, BIM, AI, and Virtual Reality to transform the UAE Building Industry. The workforce must embrace the digital and physical technologies discussed in this study to remain relevant in the market. Professionals and companies that are resistant to change risk becoming obsolete.

Therefore, it is crucial for current professionals and companies to take these findings seriously and adapt to the changes. Ultimately, this will lead to a more advanced and competitive Built Environment industry in the UAE.

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Sustainability-Specific Criteria for The Selection of Project Delivery Methods

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Abstract

Sustainable construction is more complex than traditional construction projects with unique characteristics and challenges. Choosing the appropriate delivery method is a crucial decision that can help overcome these challenges and enhance the success rate of sustainable construction projects. However, the selection criteria available in literature mainly focuses on traditional criteria such as cost, quality and time. The significance of these traditional selection criteria for project delivery methods indeed cannot be denied but this current list is far from comprehensive. Therefore, the aim of this paper is to identify and rank sustainability-specific criteria for the selection of project delivery methods. Nineteen criteria were identified that were grouped into five categories: level of integration, green liability, green contract, green team, technology and innovation. A survey was then administered to collect the perceptions of construction professionals in the United Arab Emirates about the significance of these sustainability-specific selection criteria. Thirty responses were collected and analyzed using relative importance index to identify the most significant sustainability-specific criteria. The results revealed that the top five sustainability-specific criteria include: early involvement of key participants, improve the ability to use full potential of BIM, efficiently utilize advanced technological tools to achieve sustainability, ability to use technology to enhance communication and allow for qualification-based procurement.

Keywords

Sustainable construction, Project delivery methods, Selection criteria

1. Introduction

Choosing the appropriate delivery method for construction projects has been identified by many researchers as a key ingredient for the success of the project (El-Sayegh, 2008). Delivery method is typically defined as the approach used to establish a framework of the whole design, procurement and construction processes through the allocation of different responsibilities and tasks to the project's parties in such a way that maximizes their benefits (Tenah, 2001). The most common project delivery methods that have been heavily studied and compared in literature in different countries across the world include design-bid-build (DBB), design-build (DB) and construction management at risk (CMR). DBB is also known as the traditional delivery method where two separate contracts are issued one for the contractor and one for the consultant. CMR is similar to DBB in the aspect of two separate contracts but the construction manager in CMR has the responsibilities of both a general contractor and an owner's agent. DB, one the other hand has only contract where a single entity hires both the contactor and the consultant. This allows for fast tracking as construction activities can begin during the design phase (Akpan et al., 2014; Park & Kwak, 2017).

Available literature focuses on traditional selection criteria of project delivery methods such as cost, quality and time (Oyetunji Adetokunbo & Anderson Stuart, 2006; Qiang et al., 2015). Although, one cannot deny the significance of these traditional criteria, they may not be enough to tackle the unique challenges of sustainable construction projects that are different from conventional construction. For starters, the main difference between sustainable and traditional construction is the heightened need for integrated technology in sustainable construction projects due to their interactive and multidisciplinary nature (Raouf & Al-Ghamdi, 2019). Other challenges include the need for distinct green materials and governmental approvals (Ahmed & El-Sayegh, 2022) .

Therefore, there is a need to bridge this gap in literature and derive sustainability-specific criteria for the selection of project delivery methods, to enhance the success rate of sustainable construction projects. The objectives of this research are as follows:

1. Identify sustainability-specific criteria for the selection of project delivery methods

2. Rank the sustainability-specific selection criteria according to their relative importance index

2. Materials & Methods

This study relies on a mixed method approach that combines both qualitative and quantitative techniques. The first part of this research conducts an extensive literature review to extract sustainability-specific criteria. Mixed approach was used to achieve data triangulation where the drawbacks of one method would reverse the drawbacks of the other. Nineteen sustainability-specific selection criteria were identified post extensive screening of literature with the use of specific keywords such as: selection criteria, project delivery methods and sustainable construction. The selected literature was initially filtered using their abstract to eliminate the ones that are not relevant to the topic. Full length of the retained papers was then screened to extract the sustainability-specific criteria.

While the second part was achieved through a questionnaire survey that was administered to construction professionals in the UAE. The aim of the survey was to collect the perceptions of the construction professionals on the significance of each one of the nineteen sustainability-specific criteria. The first part of the survey gathered information to help generate a respondent's profile such as years of experience, role, project type and average size of projects. While the second part used a Likert Scale of 1-5 to rate the significance of the selection criteria. Where 1 represented very low significance and 5 represented very high significance.

The Relative importance index was then calculated for each selection criterion using Equation 1 (Aghimien et al., 2018; El-Sayegh et al., 2018).

$$\text{RII}=\frac{\sum_{i=1}^{5} w_i x_i}{\sum_{i=1}^{5} x_i} \qquad \text{………………………………….. (1)}$$

Where,

w_i is the weight assigned to the ith response; w_i=1,2,3,4,5 for i=1,2,3,4,5 respectively

x_i is the frequency of the ith response

i is the response category index=1,2,3,4,5 for very low, low, average, high and very high significance respectively.

30 responses were collected as the survey only targeted respondents with either knowledge or experience in sustainable construction, where 33.3% of the respondents had 5-10 years of experience, 50% were contractors, 53.3% worked in local companies while 46.7% worked in international companies. Upon collection of data and analyzing them, the paper will also discuss the top five sustainability-specific criteria and will provide recommendations for the selection of project delivery methods in sustainable construction projects.

3. Results

3. 1 Sustainability-Specific Selection Criteria

Extensive literature review was conducted to extract nineteen sustainability-specific criteria that were categorized into five groups: level of integration, green liability. Green team, green contract, technology and innovation. The categorization of these sustainability-specific criteria followed the research done by Ahmed and El-Sayegh (2023) who developed relevant selection criteria of project delivery methods that increase the success rate of sustainable construction projects The first criteria group level of integration consists of four sub-criteria: early involvement of key participants, joint development of project goals, collaborative decision-making and control, intensified planning (Azhar et al., 2014; Korkmaz et al., 2010; Robichaud Lauren & Anantatmula Vittal, 2011).

While the second criteria group green liability consists of three sub-criteria: allow transfer of green liability, promote early assignment of green certification, promote early green guarantee. Molenaar et al. (Molenaar et al., 2009) defined green guarantee as "the point at which there is a contractual responsibility to achieve the desired green certification." The early allocation of tasks and the commitment to achieve sustainability in a project is crucial for the successful delivery of sustainable construction projects (Enache-Pommer & Horman).

Furthermore, the third criteria group green team consists of four sub-criteria: liability waivers among team players, facilitate open communication between team members, minimize adversarial relationships, capitalize on diversity and new opportunities. Having a team that is able to exchange their ideas to be able to successfully reach their shared goals of achieving sustainability outcomes is a crucial selection criterion (Franz et al., 2017; Manata et al., 2021).

Moreover, the fourth criteria group green contract also consists of four sub-criteria: allow shared risks and rewards, contractual incentive fees and awards, allow or qualification-based procurement and facilitate flexible payment provisions. Indeed, this group aims in attracting more contractors to bid for sustainable construction projects due to the presence of such contractual incentives and the flexibility to negotiate scope and cost (Ahmad & Aibinu, 2017; Xia et al., 2014).

Lastly the fifth group technology and innovation consist of four sub-criteria: capitalize on innovation, ability to use technology to enhance communication, improve the ability to use full potential of BIM and utilize advanced technological tools to achieve sustainability. In fact, researchers have claimed that maximizing the usage of BIM will not only lead to better co-ordination but also the automation of green certificate attainment and sophistication of life-cycle analysis (Brahmi et al., 2022; Bryde, 2008).

Figure 1 illustrates the nineteen sustainability-specific selection criteria.

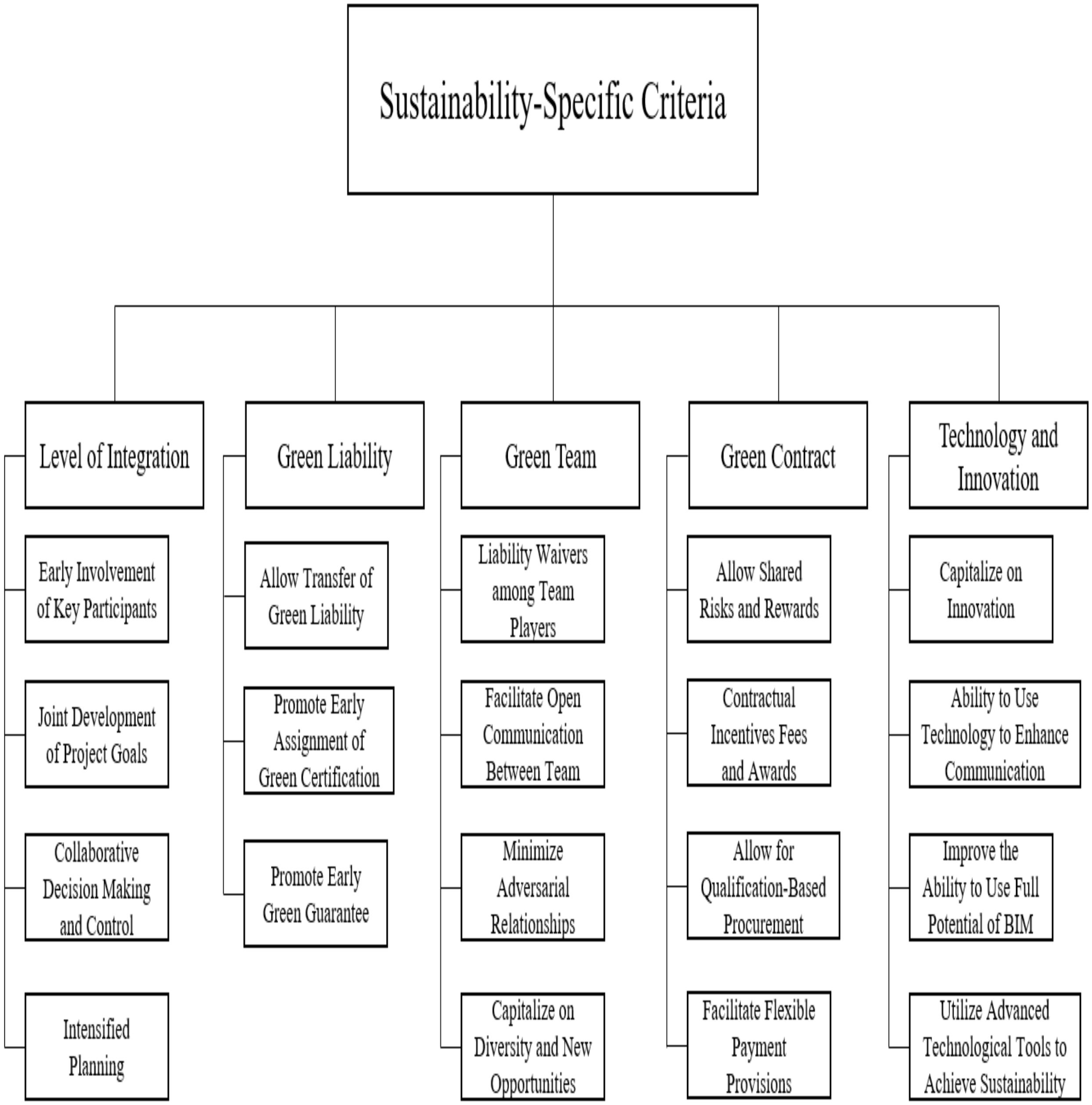

Figure 1. Sustainability-Specific Criteria

3. 2 Significance of The Sustainability-Specific Criteria

Based on the survey results, the relative importance index was calculated for each sustainability-specific criterion. The criteria were then ranked according to their RII. The results are presented in Table 1.

Table 1. RII and Rank of Sustainability-specific Selection Criteria

Sustainability-Specific Selection Criteria	RII	Rank
Early Involvement of Key Participants	4.13	1
Improve the ability to use full potential of BIM	4.00	2
Utilize Advanced Technological Tools for Sustainability	3.93	3
Ability to Use Technology to Enhance Communication	3.93	4
Allow for Qualification-Based Selection	3.90	5
Facilitate Open Communication Between Team Members	3.90	6
Capitalize on Innovation	3.87	7
Allow Shared Risks and Rewards	3.83	8
Joint Development of Project Goals	3.83	9
Collaborative Decision Making and Control	3.80	10
Allow for Transfer of Green Liability	3.77	11
Intensified Planning	3.77	12
Promote Early Green Guarantee	3.67	13
Liability Waivers among Team Players	3.67	14
Facilitate Flexible Payment Provisions	3.63	15
Capitalize on Awards and Contractual Incentive Fees	3.63	16
Promote Early Assignment of Green Certification Responsibility	3.60	17
Minimize Adversarial Relationships	3.43	18
Capitalize on Diversity and New Opportunities	3.13	19

4. Discussion

The results revealed that the top five sustainability-specific criteria were: early involvement of key participants, improve the ability to use full potential of BIM, efficiently utilize advanced technological tools to achieve sustainability, ability to use technology to enhance communication, allow for qualification-based selection. These results confirm the conclusions made by Swarup et al. (Swarup et al., 2011) who stated that involving key participants such as contractors in the early design phases of the project can have a significant impact on the successful delivery of sustainable construction projects as this leads to the creation of a collaborative environment. Moreover, the second most important criterion was the ability to use full potential of BIM. These results are in line with previous studies that emphasized the significance of data-rich BIM that simulates a virtual construction project and enhances the sustainability outcomes of the project. BIM not only demonstrates the geometry and physical properties but the whole building lifecycle with spatial relationships, fabrication and procurement information (Azhar, 2011; Ding et al., 2014).

Furthermore, the fact that three of the technology and innovation criteria made it to the top five selection criteria comes as no surprise. As, Larsson et al. (Larsson et al., 2022) have stated that the implementation of Green Mark Certified projects is positively corelated with the level of technology and innovation adopted in the project. While, the last criterion in the top 5 selection criteria was the qualification-based procurement. This indicates that construction professionals in the UAE have become more aware that the conventional lowest cost procurement approach is not compatible with sustainable construction. This is due to the fact that sustainable construction has its own unique characteristics and challenges that are different from traditional construction projects. This in turn necessitates that contactors have the proper qualification to handle these projects (Ahmed & El-Sayegh, 2022; Yudelson, 2009). On the other hand, selection criteria that made it to the bottom of the list include: capitalize on diversity and new opportunities, minimize adversarial relationships, promote early assignment of green certification responsibility.

5. Conclusions

The move towards sustainable construction has been increasing rapidly throughout the past years. Indeed, sustainable construction projects are more complex than traditional construction projects with unique characteristics and challenges. Choosing the appropriate delivery method is a crucial decision that can help overcome these challenges and enhance the success rate of sustainable construction projects. However, the selection criteria available in literature mainly focuses on traditional criteria such as cost, quality and time. Although, the significance of these traditional selection criteria for project delivery methods indeed cannot be denied but this current list is far from comprehensive as other criteria need to be included to specifically tackle the unique challenges of sustainable construction projects. Therefore, this paper identified and ranked sustainability-specific criteria for the selection of project delivery methods. Nineteen criteria were identified that were grouped into five categories: level of integration, green liability, green contract, green team, technology and innovation. A survey was then administered to collect the perceptions of construction professionals in the United Arab Emirates about the significance of these sustainability-specific selection criteria. Thirty responses were collected and analyzed. The results revealed that the top five sustainability-specific criteria were: early involvement of key participants, improve the ability to use full potential of BIM, efficiently utilize advanced technological tools to achieve sustainability, ability to use technology to enhance communication and allow for qualification-based procurement. The results of this study recommend emphasizing level of integration and technology when selecting the appropriate project delivery method for sustainable construction projects. The main limitation of this paper is the small sample size due to lack of huge database of construction professionals with experience in sustainable construction in the United Arab Emirates. This paper fills the gap in literature and paves the way to development of a comprehensive decision tool that can help owners in selecting the most appropriate delivery method for their sustainable construction projects based on traditional and sustainability-specific criteria.

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Tiny Houses – Big Learning: Impact of building industry summer camp on middle grade females

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Abstract
Exposure to STEM related careers in K-12 has increased, while the presence of females in building industry related careers has only seen moderate growth over the past several decades. Existing research has identified that exposure to STEM fields in K-12 education can have a positive impact on future career choices. The goal of this research was to explore how perceptions of middle grade female students were impacted by exposure to the AEC field through a summer camp experience. The students participated in weeklong STEM summer institute sessions hosted by a university in which students were given the opportunity to choose from a variety of session topics. This research will focus on the experiences of the students that selected the "Tiny Houses, Big Learning" session. In this session students were exposed to the different stages of the building process through the lens of a tiny house. This included activities related to architectural design, engineering, and construction processes. Students were provided the opportunity to interact with an architectural engineer and a construction manager at different times during the four-day session. Pre- and post-surveys were conducted to analyze the impact of the session on the perceptions of the female students. The surveys asked the students to self-report on their knowledge of the building industry, their interest in how buildings are built, and their interest level in a career in architecture, engineering or construction. The results of the pre- and post-survey results indicated that the female students indicated a neutral or positive increase in their knowledge and interest in the building industry and a positive increase in their interest in engineering or construction related careers.

Keywords
Female, Women, Construction Careers, Construction Education, Engineering Careers, Engineering Education.

1. Introduction
The construction industry has historically been a male-dominated sector; employment of women has risen slightly from 9.1% in 2016 (BLS, 2017) to 11.1% in 2022 (Gallagher, 2022). Although this represents a modest increase, the industry is still significantly lagging behind the overall population distribution. Over the past decade, research has shown that exposure to STEM and specifically construction education in grades 6-12 can provide opportunities for females to learn about these fields. Multiple studies have been conducted focusing specifically on exposing female high school students to construction careers (Mohany, M., et al, 2019, Escamilla & Ostadalimakhmalbaf, 2017). Additionally, research has shown that exposure to problem solving experiences (Cooper & Heaverlo, 2013) and hands-on learning (Haight, 2012) can also impact interest in STEM fields.

The aim of this research was to determine if the summer camp program increased interest in the building industry. When formulating a plan for the summer camp content, a focus on engaging female students was a priority. Middle grade students, specifically in grades five and six were selected as participants based on research indicating that interest in non-gendered careers peaks in middle grades (Lawson, et al, 2018). Existing research had identified that females pursuing a construction management bachelor's degree showed interest in hobbies that include art, crafts, and travel (Loughmiller, Keen, & Benton, 2018). Using this information and anecdotal data collected from conversations with a small group of middle grade females, the camp session was designed around tiny house living. By incorporating a topic within the building industry that was attractive to females, students would make a deeper connection with the content (Noddings & Witherell, 1991).

2. Methodology

This research is embedded within a program at xxx that encourages K-12 educators to partner with science, technology, engineering, and math (STEM) faculty to provide summer camp programming for local middle grade students, through a program called STEM Institute. The program was open to male and female students in grades five through eight, with sessions broken down by grades five and six, and grades seven and eight. The authors of this paper developed a camp session titled, “Tiny Houses / Big Learning” that would be available for grades five and six. As previously discussed, the tiny house concept tied directly to the hobbies identified as connecting with female construction management students. The camp session consisted of four days, with a three-hour session each day. Camp sessions were instructed by a female eighth grade science teacher, a female university construction management faculty member, and two students pursing their education degree. Sessions were limited to a maximum of 15 students.

2.1 Camp Session Schedule

On the first day, the students were introduced to the basics of designing and constructing a tiny house. This included video examples of the design and construction of various types of tiny houses and a brief introduction to the sustainable aspects of tiny houses. After the introduction, the students were presented with the overall project for the camp, designing a tiny house and constructing a scale model. The students were given a list of minimum requirements and a list of design and construction challenges. The challenges included different methods of incorporating sustainability into their tiny houses. The challenges were also presented as opportunities to win prizes at the end of camp.

The students would then move outdoors for an interactive activity. The students were separated into small groups and asked to tape out on the ground the actual dimensions of the tiny house they would be designing; a seven feet by twelve feet space. Once the space was defined, the groups were asked to brainstorm ideas of what to incorporate into their tiny house and draw the elements in chalk. All of the groups shared their ideas and discussed what challenges might have been created with their ideas.

To close out the first day, the students began brainstorming their tiny house design. As a part of the design process, students were asked to develop a construction budget. The budgets were developed using a combination of pricing provided to them and information they were able to gather from a variety of material purchasing websites. This stage of the process incorporated a quick refresh of basic geometry to facilitate the quantity takeoff necessary for the budgeting process.

At the beginning of the second day, students were tasked with completing their hand-drawn design and construction budget. Once those tasks were completed, the students were given access to the iPad application, KeyPlan 3D, and provided a brief tutorial on how to use the application. After completing the KeyPlan tutorial, students were asked to create a digital 3-D model of their tiny house. Students were able to expand on the design choices they made on their hand-drawn design and make adjustments to their construction budget. During the 3-D design phase, the students were asked to incorporate the challenges that were presented on day one.

The second half of this day was dedicated to a guest speaker. An architectural engineering faculty member joined the camp to share how solar power works. The students were able to interact with a solar panel, led lighting, batteries and a power inverter. One of the tiny house challenges presented on day one was to incorporate solar power, so students were able to learn which components would be required when using solar power in their tiny house design.

To start off the third day, students participated in a tool demonstration. Students were provided with safety glasses and gloves and trained on the proper use of a power saw, power drill, and a variety of hand tools. Most of the students had never had the opportunity to use the tools previously, so this provided an opportunity to expose them to carpentry. In the process of learning how to use these tools, the students constructed a scale-sized model of a table for use in their tiny house models.

The remainder of the day focused primarily on the students creating the physical 3-D models of their tiny house designs. The models were built at a scale of 1:12. Students were provided with a variety of materials, including several thicknesses of cardboard, foam, paper, fabric, and adhesives. In this phase of the camp, students were encouraged to incorporate their own personalities into the tiny houses.

The first half of the final day consisted of the students finishing the construction of their scale models. Once the model construction was completed, the group conducted a charette. Students rotated through the group presenting their completed tiny house, sharing their ideas and what challenges they attempted. The final activity of the day was the presentation of the challenge winners. Throughout the four days of the camp, the instructors discussed career opportunities in the building industry, including architecture, architectural engineering, civil engineering, and construction management.

2.2 Survey Methodology

To achieve the goals of this study, a quantitative methodology using pre- and post-surveys was conducted via Qualtrics. The pre- and post-surveys used the same group of questions. The first section of each survey addressed demographic questions of gender, age, and ethnicity. The second section consisted of the following questions:

- How knowledgeable are you about the building industry?
- How interested are you in how buildings are built?
- Would you consider a career in architecture?
- Would you consider a career in engineering?
- Would you consider a career in construction management?

3. Results

During the course of three sessions of the camp, a total of 36 students participated. Of those that participated in the camp, 10 participated in the survey process. The limited survey participation was directly impacted by the requirement for parent consent to participate. The pre-survey was conducted at the beginning of the first session of camp, prior to the introduction of content related to building industries. The post-survey was completed on the last day of camp, prior to the students leaving at the end of the session.

Data collected from the second section of the surveys were collected using a visual Likert scale. For the first two questions, related to knowledge and interest in the building industry, the scale provided was the Qualtrics visual scale “building blocks”, where 1 block indicates the lowest level and five blocks indicates the highest level. For the last three questions, related to careers, the Qualtrics visual scale “smile” was used, where the lowest level is indicated by a frown and the highest level by a smile.

Of the 10 participants, five indicated male as their gender and five indicated female. The ages of participants ranged from 11-12, which was to be expected based on the grade levels associated with participation. The ethnicity of the group identified as 90% white and 10% African American. Although the group was primarily white, this demographic breakdown does match with the community that participants were drawn from (U.S. Census Bureau, 2022).

Question 1, How knowledgeable are you about the construction industry, resulted in a mean of 3.00 for females, and 3.6 for males on the pre-survey. The post-survey results were a mean of 4.00 for the females, and 3.80 for the males (see figure 1). The results show a more significant change in self-reported knowledge about the construction industry by the females than the males.

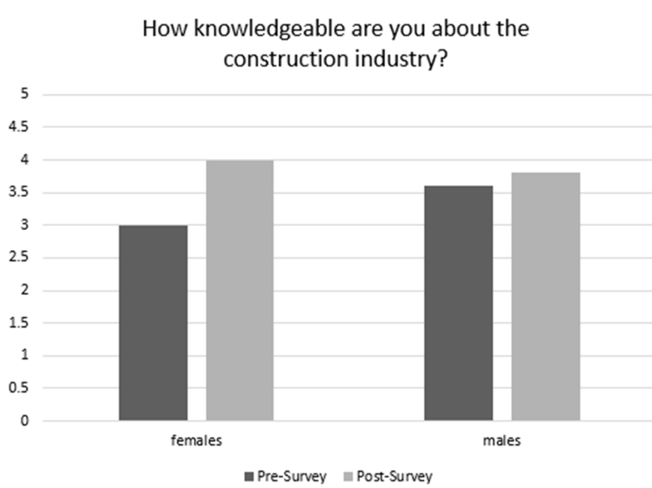

Fig. 1 Participant responses (mean) to Question 1: How knowledgeable are you about the construction industry?

Question 2, How interested are you in how buildings are built, resulted in a mean of 3.80 for females and 3.00 for males on the pre-survey. The post-survey results were a mean of 4.00 for the females and a 3.2 for the males (see figure 2). Similar to question one, the female responses showed a greater change in interest from pre- to post-survey than the males.

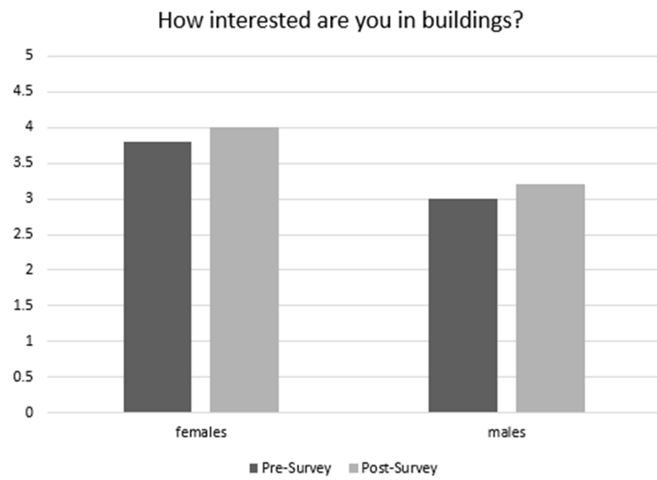

Fig. 2 Participant responses (mean) to Question 2: How interested are you in buildings?

Question 3, would you consider a career in architecture, resulted in a mean of 3.80 for females and 3.20 for males on the pre-survey. The post-survey results were a mean of 3.80 for the females and 3.80 for the males (see figure 3). The results for this question indicate no change in interest level toward a career in architecture. When analyzing the individual responses, two of the five females indicated no change, two indicated a slight increase and one indicated a negative change. This result is the only area where there was a negative response from the pre- to post- survey data.

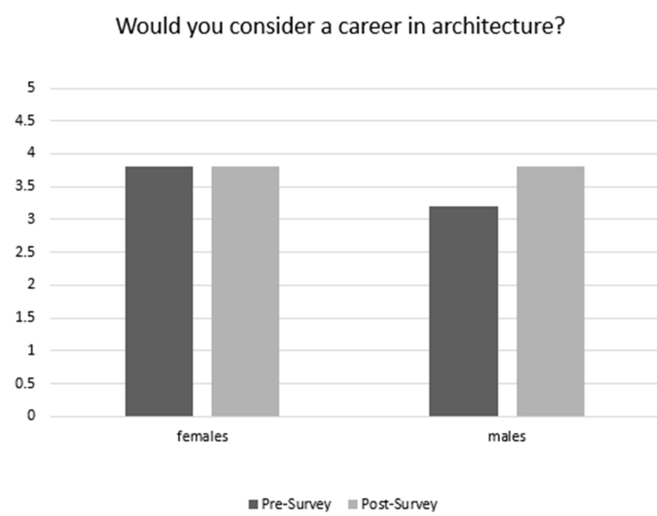

Fig. 3 Participant responses (mean) to Question 3: Would you consider a career in architecture?

Question 4, would you consider a career in engineering, resulted in a mean of 2.25 for females and 3.25 for males on the pre-survey. The post-survey results were a mean of 4.5 for the females and 3.75 for the males (see figure 4). This question represented the most significant change for the females with a doubling on the interest in an engineering career.

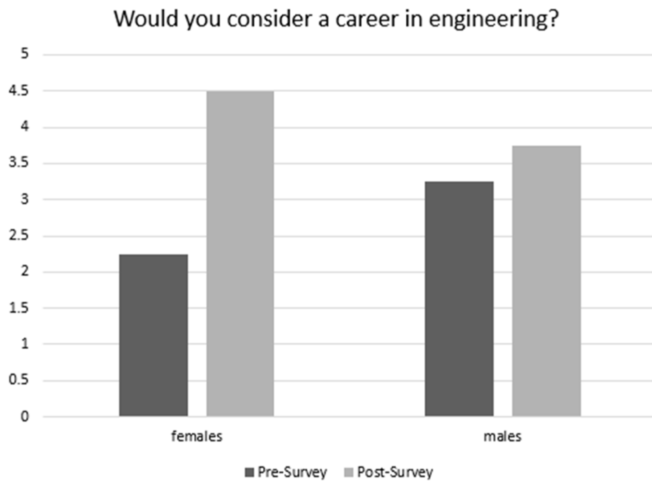

Fig. 4 Participant responses (mean) to Question 4: Would you consider a career in engineering?

Question 5, would you consider a career in construction management, resulted in a mean of 2.50 for females and 2.50 for males on the pre-survey. The post-survey results were a mean of 3.33 for the females and 2.75 for the males (see figure 5). The results of this question provide a unique set of data. The females' and males' mean responses on the pre-survey were both 2.50, while the post-survey results indicated a higher increase, 3.33, than the males, 2.75.

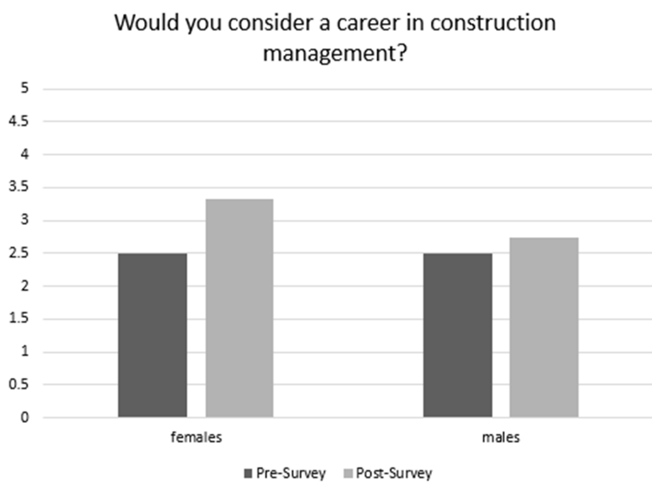

Fig. 5 Participant responses (mean) to Question 4: Would you consider a career in construction management?

Overall, nine of the ten participants showed either neutral or higher responses on all of their post-survey when compared to the pre-survey. For the student who indicated a negative response it was isolated to Question 3, would you consider a career in architecture.

4. Discussion

To address the research questions presented, the survey responses discussed above were analyzed. For the question of how did the camp influence middle grade females' knowledge of the building industry, the authors considered both questions 1 and 2. Both of these questions showed a slight increase in interest for the females over the course of the camp. For the question of how did the camp influence middle grade females interested in building related careers, the authors considered questions 3, 4 and 5. In regards to architecture as a career, the survey results indicated a neutral change in interest. For engineering and construction management a higher level of interest was reported. A 30% increase in consideration of construction management careers was identified and a 100% increase in consideration of an engineering career was identified.

5. Conclusions

The aim of this research was to determine if the summer camp program increased interest in the building industry. The study has confirmed on a small scale, that there is an increased interest in knowledge about the building industry. Additionally, it confirmed an increased interest in engineering and construction management careers. The data related to career interest could be correlated to the instructors and guest speakers associated with the camp, who represent both construction management and architectural engineering for the participants or conversely to the activities within the camp session. Although this study was limited to a small sample size of participants, the data collected confirms that exposure to the building industry does have an immediate impact on students', particularly female students', interest in the field and potential careers. This study was not able to identify if that interest level remains in the days, weeks or months after the completion of the camp. Further research, including expanding this summer camp and other similar camps, could provide a larger sample size for comparison.

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Utilization of Corncob Ash as a Partial Replacement of Cement in Concrete: A Review

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Abstract
In construction generally, cement is usually used in concrete as a binding material for construction purposes. The use of cement for concrete increases the emissions of carbon dioxide (CO_2). This emission poses a hazardous effect on humans, the environment, and the climate. Recently, there has been a move to produce lower CO_2 emissions in building projects. Using agricultural wastes such as corn cob ash (CCA) as supplementary cementitious materials (SCMs) can reduce CO_2 emission in concrete and decrease corn cob ending up in landfills. Therefore, this study systematically reviews studies in scientific databases to acquire data on these contexts. This study focused on CCA as a partial replacement for cement. The chemical and physical properties and their effect on concrete strength were investigated. Based on the contribution of scholars, it can be concluded that CCA could be used as a supplementary cementing material in concrete, from 5% to 10% of replacement without sacrificing the strength of the concrete. Also, using CCA helps solve environmental pollution caused by the inappropriate disposal of corn cob and improves concrete properties. Therefore, the findings from this study will help promote sustainability and environmental conservation.

Keywords
Pozzolan, Chemical Property, Physical Property, Sustainability, Compressive strength.

1. Introduction

Concrete is a commonly used binding material because of its strength, durability, and versatility. More than 90% of the buildings, roads, dams, retaining walls, and other structures are constructed of concrete (Patel et al., 2020), but cement; one of the constituents of concrete, consumes a large number of natural resources and energy and as well emits CO_2 during its production thereby contributing to greenhouse gas effect. Each ton of Portland cement produced emits nearly a ton of CO_2 into the atmosphere (Aprianti S, 2017). As a result, the need to protect the environment and conserve our resources has led researchers to discover agricultural and industrial wastes as cement replacement materials in concrete.

Industrial and agricultural wastes are waste generated from farming and industrial activities. According to the Food and Agriculture Organisation of the United Nations (FAO), the world maize production was 1.15 billion tonnes in 2019 (FAO, 2020). In 2018-2019, the United States was reported to be the largest maize producer, while South Africa ranks 10th as the African continent's sole producer of corn.

A million tonnes of agricultural and industrial waste are generated yearly, indicating that they are abundantly available. Therefore, the improper disposal of these wastes contributes to environmental degradation and health hazards. To solve this problem, researchers have begun to look for ways to reuse them and reduce cement's impacts simultaneously.

Some of the agricultural and industrial wastes which have been discovered by researchers as sustainable cementitious materials or partial replacements for cement in concrete production include rice husk ash (Khan et al., 2012), water lily ash (Anchondo-Perez et al., 2021), corncob ash (Olafusi & Olutoge, 2012) and (Adesanya & Raheem, 2010), Ground Granulated Blast Furnace Slag (GGBFS) (Oyebisi et al., 2021), fly ash (FA) (Nath & Sarker, 2011), coconut shell ash (Bheel et al., 2021) and many more. Abubakar et al. (2021) carried out an experimental investigation on the amount of Embodied Energy (EE) consumed and CO_2 emitted by concrete samples with cement partially replaced by CCA and those without CCA. The result revealed that the EE decreases as the CCA percentage increases. And at 20% CCA replacement with CCA, the CO_2 emission was reduced by 16.37% compared to the control concrete. This implies that the partial replacement of cement with CCA can help reduce energy consumption and CO_2 emission.

Therefore, this study seeks to review the suitability of CCA as a partial replacement for cement in concrete production as carried out by various researchers, its property, and the effect of CCA on concrete's fresh and hardened properties to promote sustainable concrete production.

2. Research Methodology

It is essential to build up a review based on past contributions of scholars in the scientific literature (Mewomo et al., 2021) as this will expose what has been covered and is yet to be covered and the future expectations in a particular study domain. Therefore, a systematic review of the past and current literature was adopted in this study to acquire data on the utilization of CCA as a partial replacement of cement in concrete. The collection of relevant academic publications related to this study's aim was obtained through Scopus and Google scholar. Inclusion and exclusion criteria were defined in searching and selecting literature pertinent to the study.

The following keywords were used: "Corn cob ash", "Corn cob Pozzolana", OR "Corn cob waste." Concise keywords are used to locate relevant articles distinctively, and 1,700 records were found. In selecting the relevant literature, inclusion and exclusion criteria were defined. The inclusion criteria were based on the practical applications of CCA as cement replacement in concrete production and its properties. At the same time, papers whose title and abstract do not correlate with the area of study and articles without the author(s) 's details and year of publication and those not written in English were excluded. After thoroughly screening the articles, 24 articles were included in the study. i.e n=24. The review process is summarized in Figure 1.

The paper is structured as follows; firstly, an introduction to the research background, followed by the methodology, the obtained findings and discussion and finally, the study's conclusions and recommendation.

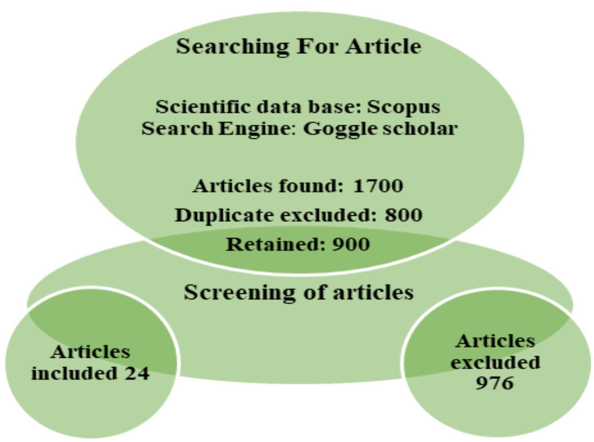

Fig. 1. A chart showing the review process.

3. Findings and Discussion

Corn, also known as maize, is a cereal crop grown worldwide as food and used to produce other products. The central cylindrical core of the corn on which the grains are attached is referred to as a corncob. Corn cob has been utilized so many ways in the construction industry; as an aggregate in the production of lightweight concrete masonry units (Cunha et al., 2015): as an alternative aggregate to produce lightweight concrete for non-structural purposes application purposes (Pinto et al., 2012) and (Helepciuc et al., 2017); as plant wastes in treatment of industrial wastewater (Ali et al., 2014), as a thermal insulation material (Paiva et al., 2012), etc. Chanadee and Chaiyarat (2016) revealed that corn cob is a good source of low-cost silicon powder when burnt in the air, an essential reactant for producing other advanced materials and many more.

Corn cob ash (CCA) material can be obtained by burning corn cob in an open field or using a kiln or furnace at a controlled temperature. Before the cobs are burnt, they are washed or dried to remove dirt and fungi. However, sometimes, they are broken into small pieces or ground before being burnt. According to Rithuparna et al. (2021), grinding the waste ash after burning increases the pozzolanic activity. Therefore, the pozzolanic characteristics of the ash obtained are influenced by the method employed in processing the ash.

In the research of Oyebisi et al. (2017), the researcher subjected the corncob to an uncontrolled (open) process of burning at a temperature of 200°C to 350°C. The ash from the uncontrolled burning process was black, indicating that the ash is of high carbon content. The resulting ash was burnt further in an industrial furnace under controlled conditions for 3hrs 15minutes until the temperature reached 650°C and kept constant for one hour to reduce the carbon content. The ash was further ground to a grain size of 90 microns. The chemical property of the ash was examined (see Table 1 for the result), and the ash was found to meet the specified requirement for class N pozzolans. Also, Chanadee and Chaiyarat (2016), in their study, burnt corn cob in the air at 600°C and 800°C temperatures. The CCA obtained at 600°C temperature looked dark grey because of the existing carbon, while the CCA at 800^0C temperature turned to milky white ash. The variation in the colour of the CCA results from the incineration time and temperature. Therefore, it can be concluded that the method employed in producing corn cob ash is essential and thus significantly influence CCA properties.

3. 1 Physical and chemical composition of corn cob ash

The physical properties of CCA include colour, size, moisture content, specific gravity, etc. In contrast, the chemical properties are the chemical constituents in the ashes, which determine the pozzolanic characteristics of the ash. CCA's physical and chemical properties depend on the burning method, time, and temperature. As carried out by researchers, CCA colour ranges from black to amorphous white. The black colour indicates the presence of excess carbon in the ash. Suwanmaneechot et al. (2015) investigated the heating temperature effect on CCA's physical, chemical, and engineering characteristics. They reported that the CCA heat treated from 200^0C to 600^0C for 4 hrs met the ASTM C618 requirement for natural pozzolans by having the sum of silicon oxide, aluminium oxide, and ferric oxide content ($SiO_2 + Al_2O_3 + Fe_2O_3$) as 72%. Also, the CCA contributes effectively to the performance of the concrete. Olafusi et al. (2018), in their research, burnt the corn cob at a temperature of 625^0C – 650^0C in a furnace for 4 to 5 hours. The ash obtained was greyish purple having a particle size of 75 microns. They reported that the oxide composition test revealed that the ash is pozzolanic as the sum of SiO_2+ Al_2O_3+ Fe_2O_3 is 64.58% which is greater than the ASTM specification for pozzolans. Tumba et al. (2018a) carried out a chemical analysis of CCA. The test revealed that CCA is a pozzolanic material as it met the pozzolan requirement stipulated by ASTM C618 and can be classified under class N natural pozzolans.

Table 1 presents CCA's physical and chemical composition as investigated by various authors. The specific gravity (SG) of CCA, as shown in table 1, ranges from 1.07 to 2.27. Still, according to the ASTM C618 specification for natural pozzolans, the specific gravity recommended for pozzolans ranges from 1.9 – to 2.44 (Neville, 1995). In addition, the chemical composition of CCA by various authors in Table 1 revealed that CCA has a high amount of silica, the constituent responsible for concrete strength. Furthermore, the variation in CCA's oxide composition in Table 1 is due to the source of the corn cob and the methods used by each author in processing the CCA.

Table 1 Physical and chemical composition of corn cob ash

Researchers	SiO_2	Al_2O_3	Fe_2O_3	CaO	M_gO	SO_3	K_2O	Na_2O	LOI	SG
Tumba et al. (2018a)	59.54	6.53	4.93	5.96	2.32	1.04	6.67	0.43	9.37	-
Ikponmwosa et al. (2015)	44.60	1.42	0.025	6.70	0.025	0.004	0.30	0.050	0.16	2.18
Kamau et al. (2016)	38.8	7.9	7.4	1.80	2.1	0.59	23.5	0.9	10.8	-
Abubakar et al. (2021)	66.4	7.5	4.4	11.6	2.1	1.1	4.9	0.4	-	2.27
Owolabi et al. (2015)	64.90	10.79	4.75	10.24	2.08	2.53	4.23	0.43	-	1.05
Oyebisi et al. (2017)	64.50	6.48	4.03	16.23	1.99	1.06	-	0.90	5.95	2.05
Suwanmaneechot et al. (2015)	63.91	4.01	3.95	4.13	2.91	0.88	12.12	-	-	-

3.2 Effect of corn cob ash on concretes workability

Concrete workability is the ease with which concrete is placed. Assefa (2019) investigated the suitability of CCA in producing lightweight concrete. Cement was replaced by CCA at 0% to 35 % at an interval of 5%. All the percentage replacement was tested for workability using the slump test. They observed that the slump value decreases as the percentage of cement replacement with CCA increases. They concluded that cement could be replaced by CCA up to 20% as the 20% slump value is still within the specified limit. Tumba et al. (2018a) studied the effect of sulphate and acid on concrete with cement replaced by CCA at 5% to 20% replacement levels. The workability of the self-compacting concrete was determined through slump tests, v-funnel, and blocking ratios. The slump and blocking ratios test result showed that the concrete workability reduces with increased CCA content. They reported that all the concrete mixes are within the range of acceptable values for the slump test except the blends with 15% and 20% CCA, while 5% replacement is suitable for the blocking ratio test. And for the V funnel test, the flow time increased as the CCA content increased. Ikponmwosa et al. (2015) partially replaced cement with CCA in concrete production from 10% to 40%. The concrete workability decreased from 79mm to 42mm. i.e., the slump changed from true to shear slump. They opined that the decrease in the workability was because of the large surface area of CCA, making the concrete demand more water to make it workable.

3.3 Effect of Corn Cob Ash on Strength Properties of Concrete

The compressive strength of concrete is determined by the quality and properties of aggregate and cement used, the concrete mix ratio, the water-cement ratio, the curing period and the handling process. Similarly, the content of CCA in a concrete mix as a partial substitute for cement influences the concrete's strength. Ikponmwosa et al. (2015) studied the strength properties of CCA concrete. The researchers investigated the effect of CCA on concrete compressive strength and flexural strength. The Cement was substituted with CCA at 0%, 10%, 20%, 30%, and 40%. The concrete mix ratio used was 1:2:4, with a water-cement ratio of 0.65. They observed that the optimum flexural and compressive strength occurred at 10% CCA content. The study recommended that concrete with 10% CCA content as a partial replacement of cement in concrete production should be used in low-cost housing construction. Price (2014) investigated the effect of the partial replacement of cement with CCA on concrete's thermal and mechanical characteristics. The cement was replaced at 0% to 20% at 5% intervals. They reported that at 90 days of curing, the compressive strength of the mortar increased to 10% replacement level and afterwards began to reduce above 10%. That is, 10% cement replacement with CCA was found to have the optimum strength (35.9Mpa). Tumba et al. (2018a) also replaced cement with CCA at 0% to 20%. The concrete cubes were cured in water, magnesium sulphate (MgSo4), and hydrochloric acid (HCl) for 7, 14, and 28 days. The result showed that 5% replacement is the optimum percentage replacement level as it offered better compressive strength. They further reported that the strength of the concrete increases with the curing age while the strength reduces as the percentage replacement of cement with CCA increases. In addition, the strength deterioration factor reduces as the CCA content increases. They opined that CCA improves the durability of concrete and can be used as a partial replacement for cement in self-compacting concrete. The result from the experimental investigation of Assefa (2019) revealed that the compressive strength of all the concrete reduced as the CCA increased. Still, the compressive strength of up to 15% replacement of cement with CCA falls within the requirement of C-25 concrete. Also, they reported that the cubes decreased in weight and became lighter as the percentage replacement of cement with CCA increased. In the study of Augustine and Michael (2016), cement was substituted with CCA at 0% to 25% in steps of 5%. The cubes were cured for 7 and 28 days and tested for compressive and flexural strength. The experimental result showed that the concrete strength decreased with an increase in the percentage of CCA content. The compressive strength of 0% CCA concrete at 28 days of curing was 27.04N/mm2 and decreased to 17.33N/mm^2 at 25% CCA. The flexural strength decreased from 10.79N/mm^2 for 0% per cent replacement to 5.72N/mm^2 for 25% replacement. They concluded that a 10% replacement of cement with CCA is optimum and suitable for building walls and other mild construction works. Singh et al. (2018) studied the effect of increased temperature on CCA concrete (M25 grade). Cement was replaced with CCA at 0%, 100%, 150%, 20% and 25%. The cast cubes were cured for 28 days and heated in a furnace at four different temperature levels, 150^{0}C to 600^{0}C, for 2hrs and tested. They detected that the compressive strength of all the percentage replacements increased up to 300^{0}C temperature and decreased above 300^{0}C temperature. They observed that the increase in strength up to 300^{0}C might be due to the increase in the hydration process, while the reduction of strength was due to the evaporation of the chemically bound water. They concluded that 10 % replacement at 330^{0}C temperature has the optimum strength. Anowai et al. (2020) partially replaced cement with CCA in varying percentages of 10%, 20% and 30% by weight in the production of Sandcrete Blocks. The Sandcrete block samples made with 10% and 20% replacements of OPC with CCA achieved compressive strengths of 4.05N/mm^2 and 2.65N/mm^2, which is within the specified by NIS:87 (2004) for sandcrete block. They recommended that OPC be partially replaced with 10% and 20% CCA in sandcrete block production for load-bearing and non-load-bearing walls, respectively. Shaikh et al. (2020) replaced cement with CCA at steps of 5% to 20%. The cubes were tested for strength at 28 days of curing. They reported that 5% replacement of cement with CCA has the maximum compressive strength (24Mpa) and split tensile strength. The compressive strength at 5% was 7% more than the control mix. And split tensile strength was 1.52% more than the control mix. Also, an experimental study was carried out by Owolabi et al. (2015) on the effect of corncob ash as a partial substitute for cement in concrete. The result revealed that at 5% cement replacement with CCA, the compressive strength was 21.44N/mm^2 at 28 days of curing. Bala et al. (2015) replaced cement with CCA in concrete production. Cubes of size 150x150x150mm were cast with cement and replaced with CCA from 0%-12% in steps of 3%. The cast cubes were tested for compressive strength at 28 days of curing. The 3% replacement for cement was found to be optimum, having a compressive strength of 29.4N/mm^2 at 28 days of curing, while the minimum strength (18.6N/mm2) was obtained at 12% replacement of cement with CCA. They recommended that superplasticizers and accelerators be used to improve the durability and strength properties of the concrete. Olafusi et al. (2018) studied CCA characteristics as pozzolans. They opined that the reduction of the compressive strength of concrete as CCA content increases could be due to the aggregation of CCA in the hardened concrete.

Table 2 presents various authors' optimum percentages of CCA for cement replacement. As recommended by the authors, the optimum ratio of CCA ranges from 3% to 15% for compressive strength and 10% for tensile strength. The recommendations of some of the authors revealed the advantages of CCA concrete. These include low-cost housing construction, lightweight concrete, self-compacting concrete, block production and building walls.

Table 2 Optimum percentage of corn cob ash by various authors

Author	**The optimum percentage of CCA**		**Recommendations**
	Compressive	Flexural/Tensile	
Ikponmwosa et al. (2015)	10%	10%	Suitable for low-cost housing construction
Price (2014)	10%	-	
Tumba et al. (2018b)	5%	-	self-compacting concrete
Assefa (2019)	15%		Suitable for Lightweight concrete
Augustine and Michael (2016)	10%	10%	suitable for building walls, beams and other mild construction works
Bala et al. (2015)	3%	-	
Anowai et al. (2020)	10-20%	-	concrete block production for load-bearing and non-load-bearing
Olafusi et al. (2018)	5%	-	
Shaikh et al. (2020)	5%	5%	
Owolabi et al. (2015)	5%	-	

4. Limitations and Further Research

The review is limited to CCA's physical and oxide composition and its effect on concrete's workability and strength properties. However, from the study, the tensile properties of CCA concrete were addressed by a few authors. Also, more investigation is needed to be carried out on the effect of corn cob from various sources, the effect of fineness on the pozzolanic characteristics, and the strength and durability properties. Furthermore, further research on CCA should address the microstructural properties of CCA concrete as it influences the strength and durability properties of concrete.

5. Conclusions

The use of corn cob ash as a partial replacement for cement was investigated by reviewing the literature. The properties of CCA and its effect on concrete strength and workability were studied. From the review, CCA is a suitable pozzolanic material for cement replacement in concrete production as its oxide composition satisfies the ASTM C618 requirement for pozzolans. However, the pozzolanic property of CCA is determined by the burning temperature, time and fineness. These properties, in turn, influence concrete strength. CCA concrete gains strength slowly, and at an earlier age, the strength is lower than that of ordinary Portland cement but increases later. Also, the strength increases with the curing period, a property of pozzolan as they gain strength with time. Furthermore, the workability of CCA concrete reduces as the CCA percentage increases, thereby requiring additional water for the concrete to become workable.

Therefore, from the review, it can be concluded that CCA could be used as a supplementary cementing material in concrete, from 5% to 10% replacement, without sacrificing the workability and strength properties of the concrete. Additionally, its utilization as cement replacement will help to enhance sustainable concrete production and promote environmental conservation.

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Mixed Reality For Teaching Concrete Formwork

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Abstract
With rapid advancements in information and communications technologies, usage of technology has become an integral part of students' life. Engaging these technology savvy students in the learning process with their preferred learning style is a challenging task. The differences in teaching and learning styles result in problems such as disengagement of students and loss of learning aptitude. This active student engagement challenge can be addressed through mixed reality (MR) learning environment. It has high potential and can play an important role to enhance students' learning experience by engaging and improving their learning attitude. This learning environment engages students in active learning processes and helps them to focus on their learning. It also encourages students to take more responsibility for their own learning process. It creates ubiquitous learning environment and provides anytime time access which facilitates the students to learn at their own pace and promotes learning beyond the regular classroom boundaries. This paper discusses an undergoing research that aims to improve the engagement and learning ability of the students through MR for learning about concrete formwork.

Keywords
Mixed Reality, Learning Environment, Engagement, Concrete Formwork, Teaching

1. Introduction

Technology became an integral part of Construction Management (CM) students' life. With further advancements of the technologies CM students the usage of the technologies for school related work will continue to grow in future. Engaging these technology savvy students in the learning process with their preferred learning style is a daunting task. The differences in teaching and learning styles result in problems such as disengagement of students and loss of learning aptitude. Additionally, the ability to visualize the built environment and learn construction processes is critical for students in the architecture, engineering, and construction disciplines [Irizarry et al, 2012; Nikolic et al, 2011]. Due to lack of experience, it will be challenging for students to visualize. Incorporating site visits in the curriculum helps the students to corroborate the learning components to the real world. Due to current COVID situation inclusion of site visits in the course became challenging. This pandemic has forced to change the teaching modality from in person face to face to online mode. This online teaching modality has added one more dimension of difficulty to engage and involve the students in the active learning environment. Some of these challenges faced by construction programs across the nation and the world can be addressed by using mixed reality (MR) learning environment. It has high potential and can play an important role to enhance students' learning experience by engaging and improving their learning attitude. It creates an interactive learning experience that mimics real world. As this learning environment involves senses of sight, hearing and touch, it leads to improved student engagement. This learning environment engages students in active learning processes and helps them to focus on their learning. It also encourages students to take more responsibility for their own learning process. It creates ubiquitous learning environment and provides anytime time access which facilitates the students to learn at their own pace and promotes learning beyond the regular classroom boundaries. This paper discusses undergoing research that aims to improve the engagement and learning ability of the students through MR for learning about concrete formwork. The paper is organized as follows:

section 2 the discusses about mixed reality and HoloLens, section 3 discusses about the MR learning environment for concrete formwork, section 4 discusses methodology for data collection and analysis. Finally conclusions are discussed in section 5.

2. Mixed Reality and HoloLens

Mixed reality (MR) is a rapidly developing technology. It was proposed by Milgram and Kishino in 1994. As shown in the Figure 1 “Virtuality Continuum” proposed by Milgram and Kishino (1994) explains the various forms of real and digital environments. As shown in Figure 1, Real Environment is on extreme left end of the continuum and Virtual Environment is on extreme right end. Real Environment describes the environment in which nothing is known about the (remote) world being displayed. This describes the real world as it is seen with one’s own eyes. In this case, no virtual computer-generated images are present. The Virtual Environment right extreme, refers to a world that the user perceives as completely virtual. This is essentially a world in which the user is 100% immersed in a virtual environment. In between “Real Environment” and “Virtual Environment” the continuum has Augmented Virtuality (AV), Augmented Reality (AR), and Mixed Reality (MR). Mixed Reality is also referred to as hybrid reality. It is the merger of real and virtual worlds which produce new environments and visualizations where physical and digital objects co-exist. It allows the digital objects to interact with real objects in real time and space. Based on three different criteria (immersion, interaction, information) MR is classified into 3iV classes: (1) it consists of both real and virtual contents and allows data contextualization; (2) the digital content is required to be interactive in real time; (3) the content needs to be spatially mapped and correlated with the 3D space [Parveaua and Addaa, 2018].

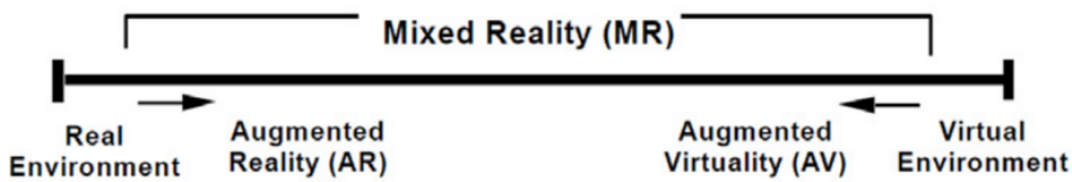

Fig. 1. Milgram and Kishio’s virtuality continuum

Microsoft Hololens is the self-contained, holographic computer. This enables to engage with the digital content and interact with holograms in the world around the user (Microsoft 2023a). It is made up of specialized components such as HoloLens Processing unit (HPU) and advanced sesnsors. These components together enable holographic computing. It’s advanced sensors capture information about what user is doing and the environment in which the user is in. It can see, map, and understand the physical places, spaces, and things around the user. It understands gestures and where user looks, and maps the world around the user, all in real time. It has a “see-through holographic high-definition lenses” and an advanced optical projection system. This generates a multi-dimensional full-color images with very low latency so that user can see holograms in their own world. It’s headband is designed to distribute the wieght around the crown of the user head and saves ears and nose from undue pressure. Headband has an adjustment wheel which ensures comftable fit for a wide range fo adult head sizes. Though it has more computing power than the average laptop, it is passively cooled without fans.Lack of wires, external cameras, or phone or PC ocnnection required makes the user to move freely (Microsoft 2023b).

Fig. 2. Microsoft Hololens (Microsoft 2018 a)

Microsoft HoloLens is useful to create mixed reality environment. It provides an intuitive and immersive environment to explore the concept of reality and human perception in a real-time perspective. It enables digital models to overlay with a real environment objects and facilitates users to interact with the digital content. The following section discusses about the MR learning environment created by the HoloLens to support teaching concrete formwork.

3. MR Learning Environment for Concrete Formwork

Formwork for concrete must be designed to support all applied vertical and lateral loads until these loads can be carried by the concrete structure itself. The goal of the research is to develop a MR learning environment for teaching concrete formwork. By enabling users to experience both the physical and virtual worlds simultaneously, this learning environment allow students to gain some of the physical exploration benefits that are possible with physical design and construction educational activities. This enables building design comprehension to support their learning. This facilitates the students to understand design assumptions, to learn about the formwork components and to learn about the formwork construction steps.

This provides environment to learn about formwork of slab, wall and column. The typical components of slab formwork are shown in Figure 3. Members which support sheathing directly are referred as joists. The cross members which support joists are usually refereed as stringers. The vertical members which support stringers are refereed as shores. The typical components of wall formwork are shown in Figure 4. Members which support sheathing directly are referred as studs. The cross members which support studs are usually refereed as wales. The wales are supported by Ties. The inclined members which are designed to resist the lateral wind loads are refereed as struts. The typical components of column formwork are shown in Figure 5. Members which support sheathing directly are referred as studs. The cross members which support studs are refereed as clamps. The inclined members which are designed to resist the lateral wind loads are refereed as struts.

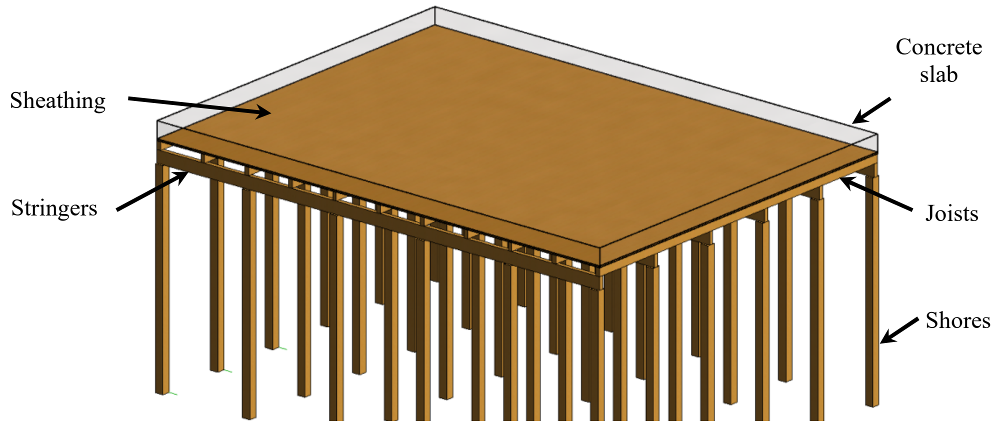

Fig. 3. Typical components of slab formwork

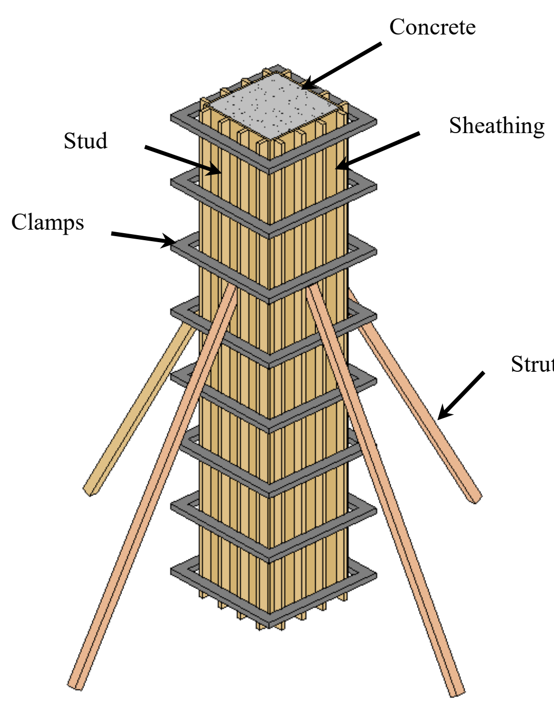

Fig. 4. Typical components of column formwork

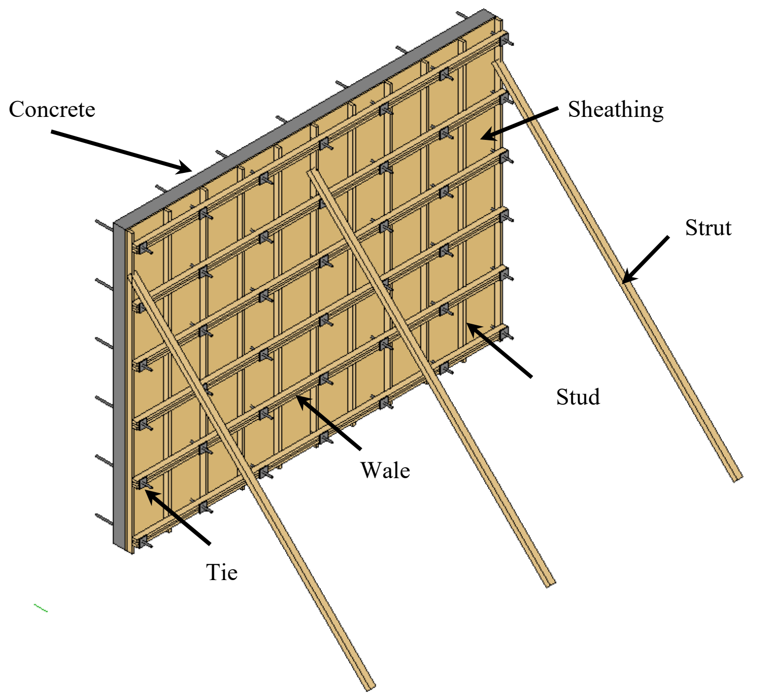

Fig. 5. Typical components of wall formwork

The 3D models of formwork of slab, wall and column created in Unity software. Unity has powerful game development engine which can work on multiplatform [Unity, 2023]. These models are exported to HoloLens with required programming scripts to create the required MR learning environment for concrete formwork. In this, environment users interact with digital models using gazing and hand gestures. The core hand gestures, including air tap, drag and bloom are shown in Figure 6. In order to implement the instructions, students have to gaze on the targeted components and to act with core hand gestures. Students can select the components of the digital model individually to investigate the component detail. The digital model can be hidden or transformed through scaling, translating and rotating, so that students can explore it from different angles and perspectives.

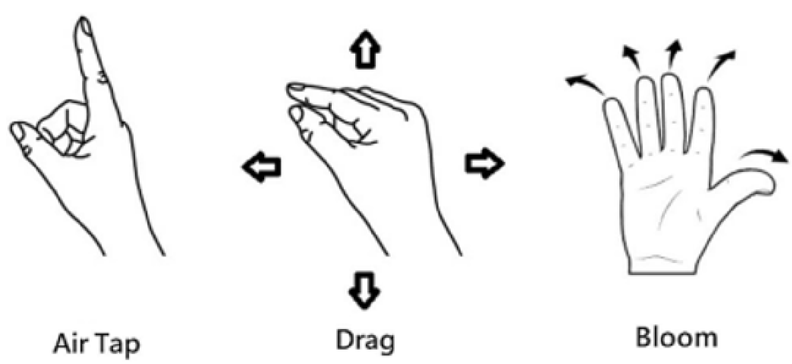

Fig. 6. Core hand gestures used in MR learning environment for concrete formwork

4. Methodology for Data Collection

One of the objectives of the study is to investigate the effectiveness of students in learning design and construction of concrete formwork through MR environment. This study plans to collect qualitative and quantitative data to sufficiently address the research objective. At the beginning of the study, two groups of students will be recruited to participate in the control and experimental groups. The control group learns with traditional 2D drawings as the sole information source. The experimental group will learn through MR learning environment. Both groups of students will be required to participate in the pretest first to quantify their abilities with respect to a certain level of understanding in design. For the experiment group, a 10min briefing and experience sessions on the operation of HoloLens will be given to familiarize with its operations. This ensures that the students can focus on learning design and construction during the test without being distracted when operating the HoloLens in MR learning environment. After the learning session, a posttest with similar difficulty will be used to assess the students' design abilities, as in the pretest. The comparison between pre and post-test surveys provides the results of the effectiveness of students in learning design and construction of concrete formwork through MR learning environment. The experimental group will also be asked to take the survey to assess the usefulness of MR learning environment to help the students to understand design assumptions, to learn about the formwork components, and to learn about the formwork construction steps. Students will be asked to express their satisfaction on these with 5-point Likert-type scale.

5. Conclusion

This work-in-progress paper introduces an undergoing research that aims to improve the engagement and learning ability of the students through MR learning environment for concrete formwork. At the time of this paper, the actual development of MR learning environment and data collection process are still ongoing. However, this paper offers a comprehensive overview of the motivation, research objective, research design and methodology, as well as data collection and analysis plan. This learning environment serves as a new teaching tool and helps to be more effective in communicating the information to the students. As this learning environment involves senses of sight, hearing and touch, and helps students to be actively engaged in the learning process. The MR learning environment has the potential to make a paradigm shift in teaching and learning process of concrete formwork. It is expected that the results and findings from this study will inform the research design and improvements in the next phase of this project.

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Comparative Review of the Living Building Challenge Certification

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Abstract

The Living Building Challenge (LBC) is a rigorous green building certification program developed by the International Living Future Institute, and it encourages the creation of buildings that are not only environmentally sustainable but also socially and economically responsible. The LBC is considered one of the most ambitious and comprehensive green building rating systems in the world. Yet, this has only been reported through individual case studies, and upon reviewing existing literature, there was a gap in comparative articles addressing successful cases on LBC certification using all seven petals of the system. Therefore, this paper aims to perform an exploratory study on reported cases of successful LBC certification. This aim will be achieved by defining LBC, and discussing the mechanisms for achieving the complete implementation of the LBC certificate. The time frame considered for this survey is between 2010 and 2023. The qualitative exploratory nature of this research focuses on reviewing databases such as Science Direct, ProQuest, Google Scholar, Research Gate, and official websites to extract relevant information using an eligibility criterion of title and abstract review, inclusion of key terms, detailed review of chosen articles and exclusion of newspaper articles, tutorials, and blog posts. The results showed five successful cases of LBC certification and discussed the seven petals of the LBC system. This work will serve as a comparative reference to aid in understanding the LBC certification and summarize the mechanisms to successfully implement the system in future work.

Keywords

Living Building Challenge, Construction, Regenerative Design, LBC, Certification.

1. Introduction

The concept of the "The Living Future", as perceived by the International Living Future Institute , is one where human species and the planet are thriving and living in a healthy and inclusive future through balance with each other and with the diverse ecosystems (*About the International Living Future Institute*, 2022). The concept of the Living Building Challenge (LBC), which is adopted by the International Living Future Institute (ILFI), a Non-Governmental Organization (NGO) that envisions a future where the planet and humanity are thriving and the society is "socially just, culturally rich, and ecologically restorative", is a philosophy in its core, an advocacy tool and a certification system. It includes the most advanced measures of sustainability that allow the positive addition to the surrounding environment and not just the reduction of negative impact (*LIVING BUILDING CHALLENGE 4.0 A Visionary Path to a Regenerative Future*, 2019), as its focus is on restoring, regenerating and adding positive impacts to the construction practices (Udawatta et al., 2021). According to the Annual Report of 2018 released by ILFI (*ANNUAL REPORT 2018*, 2018), there are more than 100 certified Living Building Challenge (LBC) Projects out of 387 registered projects , as of October 2018. Accordingly, this paper will focus on defining the Living Building Challenge (LBC) and discuss some of the successful cases of LBC certification that have been reported in literature.

2. Methods

The nature of this research is qualitative and exploratory, relying mainly on literature review. First, a targeted literature search in relevant databases (Science Direct, ProQuest, Google Scholar and Research Gate) was conducted by the authors, to identify articles that satisfy the search criterion. The Eligibility Criterion for the review consisted of an inclusion criterion, where the chosen articles should include proper definitions, explanation and applications of the living building challenge, as well as clear information about the imperatives of the living building philosophy. Resources of literature were mainly peer-reviewed articles and official websites, where needed. All included resource were in English and published between 2010 and 2023. Additionally, the Eligibility Criterion also included an Exclusion Criterion, where sources like newspaper articles, tutorials, and blog posts were from the study. The Source Identification process consisted of targeted literature search in the previously-mentioned relevant databases that was conducted by the authors using the following keywords: the living building, regenerative design and construction. Title and abstract review were the main factors to judge the content of the article. The Study Selection and Data Extraction was performed upon the satisfaction of inclusion criterion, and after reviewing the title and abstract, articles were read in details, and relevant information were extracted and drafted for further review.

3. Results

A living building can be defined as a regenerative building that provides a connection between light, food, air, nature and the occupants, while maintaining its self-sufficiency and resource limitation, and interacting positively with the surrounding natural environment and occupants. The concept of the living building challenge (LBC) was first launched by the Cascadia Green Building Council launched in 2006, followed by the establishment of the Living Building Institute to manage this project and future similar program as a result of the growing interest, which led to the formation of a partnership between Cascadia and what is now known as the International Living Future Institute (ILFI) (Gardner Haley et al., 2020). Additionally, the living building challenge is based on the concept of an efficient flower that symbolizes the ideal built environment, and has seven main performance areas (Table 1) (Living Building Challenge, 2022) with 20 imperatives that are required to achieve the Living Building Certificate (Gardner Haley et al., 2020). Also, LBC the has two main attributes (Living Building Challenge Basics, 2022): reliance on the actual instead of the modelled or anticipated operational building performance, and the holistic approach of addressing all the seven petals and their core 20 imperatives (LIVING BUILDING CHALLENGE 4.0 A Visionary Path to a Regenerative Future, 2019). These imperatives could be useful in different projects types such as construction of new buildings, renovations of existing buildings, landscape, infrastructure and community development [2]. The table below summarizes the successful achievement of The Living Building Certification in different buildings across the world:

Table 1. The seven petals of the Living Building Challenge.

Petal	Description	Imperative
Place	A healthy interrelationship with nature.	Limits to growth place Urban agriculture Habitat exchange Human-powered living
Water	Operating within the water balance of a specific climate and place.	Net positive water
Energy	Dependence on current solar income only.	Net positive energy
Health & Happiness	Optimizing physical, physiological and well-being of occupants.	Civilized environment Healthy interior environment Biophilic environment

Materials	Endorsing safe products for all species.	Red list Embodied carbon footprint Responsible industry Living economy sourcing Net positive waste
Equity	Supporting an equitable and just world.	Human scale & humane places Universal access to nature and place Equitable investment Just organization
Beauty	Adopting designs that elevate human spirits.	Beauty and spirit Inspiration and education

A building must achieve seven performance criteria, commonly referred to as petals, in order to receive the LBC certification and be deemed a "Living Building." Place, Water, Energy, Health, Materials, Equity, and Beauty are the seven petals. A building must satisfy all of the performance standards in each of the seven petals for at least 12 continuous months of operation in order to get Living Building Challenge certification (Challenge et al., 2010; Whitaker et al.). Across the world, more than 35 Living Building Challenge projects have received certification. Of these projects, almost a dozen has received certification in all seven petals, proving that they have complied with all 20 Living Building Challenge requirements (imperatives). The remaining projects that have received certification have done so in one or more of the petals, but not in all seven. Becoming certified in all seven petals is a noteworthy achievement given that the Living Building Challenge is a very demanding and hard certification procedure. The projects that have attained the level of full certification are pushing the limits of environmentally friendly design and building, and they are motivating others to follow suit. These projects, which can be found all over the world, exhibit a variety of sustainable design and construction techniques, such as water conservation, the use of renewable energy sources, sustainable building materials, and community involvement. They demonstrate what is possible when sustainability is prioritized in building design and construction by serving as motivational models (Challenge et al., 2010; I. L. F. Institute; Whitaker et al.). The following table will examine some of the projects that got full living building challenge certification in all the seven petals:

Table 2. Five successful cases of implementing the Living Building Challenge

Petal	Sustainable Building Research Centre (SBRC) in Australia	Te Kura Whare in New Zealand	The Bullitt Center in USA	The Omega Center for Sustainable Living in USA	The Tyson Living Learning Center in USA
Place	Historical place, landscape design to restore indigenous vegetation on Dharawal lands, gardens include indigenous plant species used as food, fiber, tools, or medicine, offsetting ecologically valuable sites in Pullen Pullen Reserve, promotes car-free living	Natural environment with native flora and animals, utilizing local resources, having a green roof with native plants, structure created to blend in with its surroundings, bike storage and close to public transit.	Close proximity to public transit, walkability, and bike-ability, since it is located on a previously built site in an urban setting, with a pedestrian-oriented design.	Constructed on a previously developed site negates the need to destroy undeveloped land.	Blending with existing campus fabric, access to public transit, constructed on existing site, reducing requirement to develop undeveloped land and surrounded by a restored natural environment.
Water	Green roof with a harvesting system is implemented to gather roof rainwater and stores in subterranean tanks, it also has a bioswale to control stormwater. All non-potable demands, including irrigation, toilet flushing, and building cooling, are met	Rainwater harvesting, on-site wastewater treatment, reuse of all sewage, applied low-flow fixtures and appliances. The building's water usage is completely self-sufficient.	Controlled stormwater runoff, building wouldn't have an adverse effect on the area's wildlife, rainwater harvesting system and water-saving amenities including	Stormwater management techniques(rain gardens and bioswales), complex system for collecting and filtering rainwater, to be utilized for	Rainwater management system for use in the building's restrooms and irrigation systems. Also, the structure includes a green roof which lowers

	with this water collected and managed		low-flow toilets and sinks	all non-potable water requirements, structure uses a Living Machine, (on-site natural wastewater treatment system) to handle sewage.	stormwater runoff and enhances water quality.
Energy	The SBRC used a variety of sustainable energy solutions, including solar photovoltaic panels, a geothermal heat pump system, and a solar hot water system. The structure is a net-zero energy building since it produces more energy than it consumes.	Net-zero energy structure. The structure incorporates both active and passive design elements, including solar panels and a ground-source heat pump, as well as natural ventilation and building orientation and energy-saving equipment and lights.	Using solar energy to meet 100% of its energy demands. The building also has energy-efficient design features including daylighting and natural ventilation.	Utilizing a mix of solar panels, geothermal heating and cooling, and a micro-hydro turbine to generate all of the building's energy requirements.	Energy-efficient features (geothermal heating and cooling), a high-performance building envelope, energy-efficient lighting and appliances, structure features a rooftop solar array that supplies some electrical requirements.
Health & Happiness	Using natural light, interior plants, and a fresh air ventilation system. Access to nature is made possible through the building's rooftop garden, outdoor yard, and green wall.	Built with plenty of natural light and ventilation to enhance indoor air quality. The structure is made of non-toxic materials, and all of the furnishings and equipment were carefully chosen to adhere to high standards for health and safety.	Incorporating natural daylighting, fresh air ventilation, and non-toxic building materials	Using organic materials in structure (clay plaster and bamboo flooring), cutting-edge ventilation system with access to fresh air, a policy of exclusively employing non-toxic cleaning supplies.	Utilizing non-toxic building materials and finishes, as well as offering enough of natural light and fresh air ventilation, TLLC complies with the health requirement. Also, the structure features a range of indoor and outdoor spaces
Materials	Using FSC-certified timber, recyclable steel, and low-VOC paints and finishes. A recycled-materials green wall is another aspect of the structure.	Constructed using non-toxic, locally produced, and recycled materials. 4Te Kura Whare has a green roof composed of native plants that helps to enhance air quality and minimize stormwater runoff, as well as a living wall built of recycled materials.	Incorporating environmentally friendly, non-toxic materials including recycled steel and FSC-certified wood. A materials recovery program to recycle and reuse construction materials is also a part of the building.	Using range of ecological materials, including insulation with recycled content and wood from the neighborhood. The structure also has a policy requiring all waste produced on-site to be recycled or composted	Reclaimed wood, carpet with recycled content, low-VOC paints and finishes. Also, the building has a "red list" of materials that forbids the use of specific hazardous or poisonous substances.
Equity	Adopting universal design principles to guarantee the structure is friendly to those with disabilities. The structure also offers a place for community activities and	Accessible parking to all. A community meeting room is also available in the building and is open to use by neighborhood	The structure was created to be open and friendly to everyone, irrespective of their socioeconomic situation or	The OCSL was intended to be a community resource, with classes and meeting rooms available for use by	Public access to the structure's facilities and inclusion of educational and community outreach initiatives that advance sustainability and

	educational programs that supports social equity.	communities and groups.	physical capabilities. The building has community areas and educational facilities open to all.	nearby groups and schools, it also has a rule requiring that all staff get a decent wage.	environmental awareness.
Beauty	Adopting a variety of lovely and inspirational elements, such as a green wall, a rooftop garden, and a central atrium that lets in natural light and ventilation.	Designed and built to be a lovely and inspirational venue that represents the local culture and environment where it's made out of natural materials like wood and stone and combines artwork and design cues that honor the Maori culture.	Designed and built to be visually beautiful and to mix in with the community it is located in.	Constructed using principles of biophilic design in mind, which means that it includes natural features into its design, such as views of the surrounding countryside and natural daylighting. It also has a living wall which is basically a vertical garden that serves to filter the air and provide a soothing environment.	Green roof, rain gardens, and a natural material palette. A number of public areas throughout the structure also promote social interaction and community involvement.
References	(Architecture; I. L. F. Institute; McCarthy & Rasekth, 2013)	(I. L. F. Institute; Partington & Zari, 2020)	(I. F. L. Institute; Mirel, 2014)	(Fulton et al., 2011; I. L. F. Institute)	(I. L. F. Institute; Lee et al., 2013)

4. Discussion

The Sustainable Buildings Research Centre (SBRC) at the University of Wollongong achieved Living Building Challenge (LBC) certifications across all the 7 petals. The site petal requirements were met by restoring indigenous vegetation, creating urban agriculture areas, offsetting ecological damage, and providing alternative transportation options (car free). The water petal requirements were met by achieving the net zero water imperative through minimizing water use and using captured rainwater which is treated through filtration and ultraviolet sterilization and by achieving the ecological water flow imperative through treating all water discharged from building occupant activities and storm water through natural processes, where this water is treated in a three-stage process and used to irrigate the surrounding landscape via subsurface irrigation, the building also employs stormwater harvesting, bio-retention, and a constructed wetland. The energy petal certification was achieved through a strong focus on passive design, low energy heating and air conditioning, and sophisticated lighting control. Once energy targets were met, a rooftop solar array consisting of nearly 600 panels was installed with on-site battery storage. A shared energy system was also established with neighboring university buildings, with excess power exported to the grid. The SBRC also pioneered the use of a unique Photovoltaic Thermal (PVT) system and collaborated with the electrical utility to enable PV arrays of intermediate scale to be accommodated. The health and happiness petal requirements were met by maximizing the natural ventilation for fresh air exchange, with narrow floor plates and large, openable windows for excellent cross ventilation, meeting the Civilized Environment Imperative and by designing the building to be naturally ventilated for 95% of the habitable areas and having a ventilation rate designed in accordance with AS 1668.2, which has more stringent requirements than ASHRAE 62. Biophilic design is also incorporated, with each of the six established Biophilic Design Elements represented into the building in at least two ways, including natural shapes and forms, natural patterns and processes, light and space, and place-based relationships. The materials petal certification was achieved by using a dematerialization strategy and selected locally sourced and reused materials to mitigate embodied carbon. All timber used was either FSC certified or obtained from salvaged sources, and a Material Conservation Management Plan was implemented to eliminate waste during the building's life cycle. Also the performance criteria for materials had to be carefully balanced, leading to the use of a spray-applied paper pulp product for insulation with lead, PVC, and formaldehyde exemptions. The equity petal certification was achieved by prioritizing sustainable solutions for retrofitting existing buildings, encouraging active and human-powered transportation, removing barriers between the university and wider community, providing publicly accessible spaces and complying with accessibility standards. Additionally, the SBRC did not block access to sunlight or natural waterways and did not emit harmful chemicals. The beauty certification was achieved through its design to connect with visitors, showcasing research through exhibition spaces and windows, and creating an outdoor space for relaxation and connection with the environment. It has also become an educational and inspirational facility, featuring interpretive signage, visible building services, and being used as a national test-case for LBC auditors. The SBRC hosts various groups and individuals, including politicians, influential people, and school groups, and has showcased its research through annual public open days.

Te Kura Whare in New Zealand achieved Living Building Challenge (LBC) certifications across all the 7 petals. The site petal requirements were met by transforming a rural farmland into a cultural civic zone, integrating a range of agriculture opportunities and selecting endangered and native plant species for planting, recognizing the role and responsibility to regenerate life within the building community and promoting walking and biking for local residents, purchasing hybrid vehicles for staff, and acknowledging the challenges of car-free travel for visitors. The water petal requirements were met by collecting rainwater and storing it in two 25,000-liter tanks, providing all the building's water needs. Potable water is filtered and UV-treated, with estimated monthly use of 40,000 liters. Black water is treated by a botanical wastewater treatment system and discharged on site, while stormwater is stored in a pond capable of retaining 3000 m^3 and disperses into the water table via built soak pits. The energy petal certification was achieved by implementing a variety of sustainable strategies. The building features passive solar design with north-facing glazing, shading, and thermally broken double glazing to minimize heat loss/gain. The facility also uses photovoltaic panels for energy production, a battery bank for storage, and energy-efficient split system heat pumps for heating. Additionally, the building employs solar hot water systems and energy-efficient equipment to minimize electricity consumption. Lighting is controlled by a fully automated system with energy-efficient fixtures, and the security system includes access control and CCTV cameras. The health and happiness petal requirements included using operable windows in all spaces, requiring reduced floor plates and internal access routes and by using natural materials that reflecting the connection to the land and environment, with natural logs used as posts, beams, and trusses to emulate the forest canopy. The building has different programs and uses, with various penetration points for natural lighting and warming, stimulating positive emotional senses for better user experiences. The materials petal certification was achieved by producing a practically Red List-free specification, using innovative solutions in structural engineering, and raising awareness amongst suppliers through advocacy letters. Also, the design of this building focused on managing the carbon footprint by sourcing materials locally, calculating the embodied carbon footprint, and investing in local sustainable projects. The equity petal certification was achieved by offering hospitality, serving modern classic cuisines with culture, providing facilities for small and conference-sized meetings and events. The absence of front boundary fencing and ample parking space allows for an inviting impression, and the open-plan approach continues within the building. The external community space provides a place for people to congregate, relax, and enjoy Maori traditions. Mature trees and boundary embankments provide shaded areas and shield the sound of traffic. The beauty certification was achieved by incorporating Tūhoe tikanga in the building process, creating a legacy for Tūhoe, and pushing boundaries to create hope and inspiration. Overall, the building provides learning opportunities for community members to implement home-scale projects and leaves a legacy of contribution.

The Bullitt Center in USA achieved Living Building Challenge (LBC) certifications across all the 7 petals. The site petal requirements were met by a site that had a one-story building and a parking lot, but instead of demolishing them, the team secured approval for deconstruction and material reuse. They also equipped the building with a bike garage and showers to promote human-powered transportation. The water petal requirements were met by using rainwater collected from the roof, which was diverted into a cistern, and harvested greywater. These sustainable systems met the demands of a growing population with innovation. The energy petal certification was achieved by using solar energy to meet 100% of the energy demands, the building also has energy-efficient design features including daylighting and natural ventilation. The health and happiness petal requirements were met by prioritizing occupant health through design elements such as the 'irresistible' stair that encourages exercise and offers stunning views. Natural daylight and views are available to every workstation, and low and zero VOC finishes contribute to healthy air quality. The Bullitt Center achieved LBC certification in the Materials petal by implementing a successful collaboration between the developer, contractor, and sub-contractors for the materials vetting process. Red List substitutions were made and the embodied carbon footprint was reduced by 3,000 metric tons. Wood sources were FSC certified and salvaged, and living economy sourcing was prioritized with notable regional products. The equity petal certification was achieved by prioritizing ongoing community outreach, education, and public tours to advance the green building industry. It has also worked with all levels of government to identify and lower barriers to entry for future high-performance structures. The beauty certification was achieved by the building being designed and built to be visually beautiful and to mix in with the community it is located in.

The Omega Center for Sustainable Living (OCSL) in USA achieved Living Building Challenge (LBC) certifications across all the 7 petals. The site petal requirements were met by selecting a previously developed site that negates the need to destroy undeveloped land. The water petal requirements were met by adopting stormwater management techniques like rain gardens and bioswales. OCSL has a complex system for collecting and filtering rainwater, to be utilized for all non-potable water requirements. The structure also uses a living machine, a type of on-site natural wastewater treatment system, to handle all of its own sewage. The energy petal certification was achieved by utilizing a mix of solar panels, geothermal heating and cooling, and a micro-hydro turbine to generate all of the building's energy requirements. The health and happiness petal requirements were met by using organic materials all around the structure such as clay plaster and bamboo flooring and by adopting a cutting-edge ventilation system that gives all residents access to fresh air. Also, the facility has a policy of exclusively employing non-toxic cleaning supplies. The materials petal certification was achieved by using a range of ecological materials, including insulation with recycled content and wood from the neighborhood. The structure also has a policy requiring all waste produced on-site to be recycled or composted. The equity petal certification was achieved as The OCSL was intended to be a community resource, with classes and meeting rooms available for use by nearby groups and schools, it also has a rule requiring that all staff get a decent wage. The beauty certification was achieved by using principles of biophilic design which means that it includes natural features into its design, such as views of the surrounding countryside and natural daylighting. It also has a living wall which is basically a vertical garden that serves to filter the air and provide a soothing environment.

The Tyson Living Learning Center in USA achieved Living Building Challenge (LBC) certifications across all the 7 petals. The site petal requirements were met by selecting a previously developed parking lot and transforming it into a sustainable building designed with wildlife in mind. The site's habitat was improved significantly by introducing a rain garden and landscaped area that replaced impervious surfaces and runoff into an ephemeral stream. The water petal requirements were met by meeting the net positive water imperative. The building uses harvested rainfall from a 3,000-gallon cistern and a sloped standing seam metal roof. The domestic water distribution is fed from the rainwater system, and grey water from sinks and irrigation is also fed into the system. The requirements of the energy petal certification were met by achieving net zero energy through a whole building approach, maximizing efficiency and on-site energy production. Traditional and non-traditional methods were used, including high-efficiency glass, shading, natural ventilation, lighting controls, and energy appliances. The health and happiness petal requirements were met by considering indoor/outdoor connection with natural daylighting and views to the outdoors. Zero VOC paints and low/zero VOC wood finishes were used to minimize toxins, while permanent walk-off mats captured particulates at entry points. The janitor's closet was separately ventilated, and a green cleaning program was established. The building sourced non-chemically treated rainwater for drinking, and the restrooms had views, operable windows, and a solar tubular skylight for natural lighting. The materials petal certification was achieved by using sustainable materials available at the Tyson Living Learning Center, where it is located. The wood harvested from the property was chosen from storm-downed or dead trees near roads to minimize disturbance to the ecosystem, and invasive species were used for exterior siding, trim, flooring, and casework. The building also had to meet the LBC red list imperative, which required finding products free of hazardous materials such as lead and formaldehyde. The embodied carbon footprint imperative was achieved through the Tanaka Wind Farm project, while responsible industry imperative was met through sourcing FSC-certified wood and products. The beauty certification was achieved by having green roof, rain gardens, and a natural material palette. A number of public areas throughout the structure also promote social interaction and community involvement.

The new way of rethinking design in light of the emergence of the living building concept has given rise to certain topologies to be considered when choosing to apply the concept to any project, which include: Renovation (work that does not entail complete reconstruction of an existing building) Landscape or infrastructure (non-physical structures such as open park-like areas, bridges, roads, plazas or amphitheaters) and buildings (construction of a new or existing roofed and walled structure for permanent usage) (LIVING BUILDING CHALLENGE 4.0 A Visionary Path to a Regenerative Future, 2019). As such, projects that fall into one of the previous categories and successfully implement the relative imperatives of the Living Building Challenge can be considered the “greenest” projects. However, there is another aspect that needs to be addressed, which is the possible impediments for investing or implementing the living building concept, and that includes the high cost of making a living building or achieving net zero energy, as well as the challenge in finding the suitable sustainable materials to achieve the intended imperatives (Hegazy et al., 2017). Therefore, there is still a gap in both literature and the industry on the comprehensive understanding of the implementation of the Living Building Challenge, especially in the MENA region and the Arabian Gulf countries, like the United Arab Emirates. This is mainly due to the hot arid climate of this geographical area and the harsh environmental conditions, not to mention the unique geographical elements like the desserts, natural mountains, rocky shores and long summer seasons, in addition to the demanding urban lifestyle in the major cities like the high consumption of water and electricity and the high carbon emissions due to using fuel-operated vehicles. Accordingly, the topic of the Living Building Challenge requires much-needed research in the MENA region, by exploring how the concept of biomimicry (imitating nature) can be integrated into the design and build process of new buildings that can achieve the LBC certification.

5. Conclusions

The Living Building Challenge (LBC) is a demanding certification scheme that sets the bar high for environmentally friendly construction methods. The LBC establishes high performance standards for buildings to fulfil or surpass in terms of energy, water, health, and other sustainability indicators. The Living Building Challenge is significant because it pushes buildings to actively contribute to a world that is healthier and more resilient, while simultaneously reducing the environmental footprint. Additionally, the LBC encourages sustainable and regenerative design; The LBC strives to design and build buildings that have a net-positive impact on the environment by generating more energy than they consume, collecting and reusing water, and using non-toxic and sustainable materials. This approach to building design can assist to lessen the environmental effect of the built environment, and progress towards a more regenerative and sustainable future. The LBC focuses on elements including interior air quality, access to daylight and fresh air, and the use of non-toxic materials in order to take into account the health and wellness of building occupants. Those who live or work in living buildings may benefit in terms of productivity, comfort, and general wellness as a result. It promotes justice and community. This involves making inclusive, inviting venues that are accessible for individuals of all ages, abilities, and backgrounds. LBC-certified buildings are further urged to support the neighborhood by offering public areas and services, therefore establishing a high bar for architectural design; The LBC also raises the bar for building design, pressing designers to go above and beyond the requirements of conventional building standards and regulations. Designers and builders may push the envelope of sustainable building techniques and produce structures that are really new and ground-breaking by aiming to achieve the LBC's performance standards. The Living Building Challenge is significant because it upholds a high standard for building design, prioritizes health and wellbeing, creates community, and promotes fairness. The LBC may contribute to the development of a brighter future for everyone by supporting the creation of structures that are both ecologically responsible and socially useful. Nevertheless, further research regarding the applicability of LBC certification in the MENA region is highly encouraged to enrich the body of knowledge and further the understanding of such a philosophy among the relevant stakeholders in Architecture, Engineering and Construction (AEC) fields and the building occupants, wither being residential or commercial buildings.

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Evaluating the Implementation of Machine Learning Techniques in the South African Built Environment

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Abstract

The future of machine learning (ML) in building may seem like a general idea that will take decades to materialize, but it is far closer than previously believed. In reality, the built environment has progressively increased interest in machine learning. Although it could appear to be a very technical, impersonal approach, it can make things more personable. Instead of eliminating humans from the equation, machine learning allows people to do their real work more efficiently. It is, therefore, vital to evaluate the factors influencing the implementation of machine learning techniques in the South African built environment. The study's design was one of a survey. In South Africa, construction workers and professionals were given one hundred fifty (150) questionnaires, of which one hundred and twenty-four (124) were returned and deemed eligible for the study. The collected data were analyzed using percentages, mean item scores, standard deviation, and Kruskal-Wallis. The results demonstrate that the top factors influencing the adoption of machine learning are knowledge level and a lack of understanding of its potential benefits. In comparison, lack of collaboration among stakeholders and lack of tools and services are the key hurdles to deploying machine learning within the South African built environment. The study concluded that ML adoption should be promoted to increase safety, productivity, and service quality within the built environment.

Keywords

Machine learning, Implementation, Built environment, Construction Stakeholders

1. Introduction

Machine learning (ML) and artificial intelligence (AI) are two examples of digital tools. The whole point of ML is to use computers or other technologies to perform activities that often need human thought (Brynjolfsson & Mitchell, 2017). Moreover, machine learning, a subset of AI, recognizes data trends using mathematical algorithms based on statistical models to make predictions or provide descriptions (Sarker, 2021). It's important to recognize that learning is the process of turning experience into knowledge that can be applied generally. The concept of machine learning was highlighted by Kudelina et al., (2021) in that a computer is programmed using a particular mathematical model (fit on example data or historical data), developed using statistical techniques, to automatically suggest solutions to the user when problems arise, without the user having to provide solutions or anticipate them for all situations. Additionally, these mathematical algorithms are computer-understood instructions that tell computers how to convert inputs into outputs. As a result, these algorithms make sure that statistical models are fitted to data in order to explain the data and produce useful information that can be applied in the real world.

Data-driven machine learning techniques are not a recent development. The fundamental ideas behind ML rely on example data or previous data (Ihme et al., 2022). This data can be in a variety of formats, including video, sensor, text (both historical and current), and numerical. Several techniques that operate on a set of guiding principles can be used interchangeably on data and are not constrained to a particular format. There are primarily two uses for these machine learning techniques (Wan et al., 2020). This is specifically for learning from historical data and making predictions (or learning) about current occurrences based on that knowledge. Moreover, there are two categories that can be used to differentiate between various machine learning algorithms: supervised learning (SL) and unsupervised learning (UL) (Siam et al., 2019). Algorithms that fall under the SL category must learn how to map inputs to their appropriate outputs using a labelled dataset that is provided by a supervisor. Similar to this, algorithms in UL are simply supplied input without a supervisor. Regressions and classification are SL techniques, but clustering is an unsupervised learning technique. Regression and clustering are the machine learning techniques most frequently employed in the construction sector, according to Bilal et al., (2016). These techniques are frequently used in conjunction with other machine learning (ML) techniques including natural language processing (NLP) and information retrieval, however depending on the data that is available, ML techniques can also be employed alternately.

Since the adoption of ML approaches in developing nations like South Africa has been obviously lagging, numerous studies on the application of ML algorithms in the construction industry have been done remarkably in rich countries (Carbonneau et al., 2008; Musumeci et al., 2019) . Also, substantial study was done on the use of ML approaches in construction (Mirzaei et al., 2022; Baduge et al., 2022). This can be divided into two distinct parts. The first part focuses more on knowledge extraction by creating a program that can be used to extract and acquire key details about different accidents and their attributes. The second part involves using the ML method to predict the nature of accidents and the potential types of injuries they may cause. Natural language processing tool (NLP), a machine learning algorithm, can be used to extract knowledge from accident data. Use machine learning techniques, such as random forest (RF) and stochastic gradient boosting (SGTB), which employ an algorithm to build regression and classification models to predict the type of injury and the type of energy. The system can also be used to forecast which body part, under specific conditions, is most likely to sustain damage. With this understanding, safety precautions can be adopted and applied correctly.

In a review, Hegde & Rokseth, (2020) provided examples of standard machine learning (ML) approaches that can be used to support risk assessment in the construction sector. These approaches include classification algorithms like ANN, SVM, DTs, and others. Input data sources for ML models used in risk assessment in the construction industry were described in the paper. The Occupational Health and Safety Act (OHSA) provided the following text-based injury and incident reports, videos, photographs, and accident data (Fang et al., 2020). The use of other algorithms including stochastic regression, multiple regressions, evolutionary algorithms, and nave Bayes in the construction industry was comprehensively defined by Baduge et al., (2022). Unsupervised learning has been used in various construction-related applications, despite the fact that the majority of research in the field has centered on supervised learning techniques. By examining how machine learning methods are used in the South African built environment, this work advances the study of machine learning approaches.

2. Methods

This study was started to assess how machine learning techniques were being used in the built environment. The use of a quantitative methodology inspired the survey design, which led to the use of a structured questionnaire survey. Closed-ended questions designed to elicit feedback on the application of machine learning techniques in the construction industry were utilized in the structured questionnaire created by Adekunle et al., (2022). The study's participants are academics and professionals from the South African construction sector who work for various organizations. For data gathering within the study population to obtain wider coverage, the study used random sampling and a snowball sampling approach. The questionnaire In order to obtain enough data, one hundred and thirty-five (135) questionnaires were retrieved after being distributed from April 2022 to October 2022, and each one was evaluated for analytic readiness. The questionnaire was split into two sections: one half evaluated the respondents' demographics, and the other gave respondents access to a myriad of factors impacting the adoption of ML as gleaned from a thorough assessment of the literature. The dependability of the research tool was assessed using Cronbach's alpha. The study's research instrument's reliability was demonstrated by the value of 0.875 that was obtained.

3. Results

According to the respondents' backgrounds, 26% of them were academicians, 10% were architects, 7% were electrical and electronics engineers, 10% were mechanical engineers, 17% were civil engineers, 14% were quantity surveyors, and 16% were project managers for construction. 30% of respondents have one to five years' experience, 54% have six to ten years' experience, and 16% have between eleven and fifteen years' experience.

The parameters impacting the adoption of machine learning in the built environment are displayed in table 1 below, going from greatest mean to lowest mean. As can be seen, measures with the same mean were ranked according to how much they deviated from it (standard deviation, or SD). As compared to the mean value of the set, the standard deviation (SD) measures the degree of scattering in a set of data. A big SD is the consequence of data that deviates significantly from the mean, whereas a small SD indicates that all of the values are relatively close to the mean. In order to compare respondents' perspectives based on their years of experience, a Kruskal-test Walli's was also done. The complexity of ML results and trend visualisation, two factors impacting the adoption of ML in the South African built environment, were shown to not significantly deviate from the mean values. This is due to the fact that the p-values are higher than 0.05, which is consistent with a study by Greenland et al., (2016) that found no significant difference between variables with p-values more than 0.05 and vice versa. The mean values of each group of respondent are statistically different for the other parameters.

Table 1. Factors influencing adoption of Machine Learning

Identified factors	$\bar{x}$	σX	R	P-Values
The Level of knowledge of ML methods	4.04	0.947	1	0.048
Potential benefits uncertainty	3.88	0.895	2	0.000
Characteristics of a dataset	3.86	0.857	3	0.000
Complex nature of ML results	3.86	0.808	4	0.629
The level of formal education	3.86	0.923	5	0.032
The choice of ML technique to use	3.86	0.948	6	0.028
Accuracy	3.86	1.050	7	0.045
Level of trustworthiness in the ML algorithm	3.80	0.833	8	0.000
The Heterogeneous nature of data	3.80	0.969	9	0.000
Understanding digital technology	3.80	1.030	10	0.013
Data quality	3.76	1.098	11	0.005
Trend visualisation	3.72	0.882	12	0.088
User interface of ML tools	3.70	0.863	13	0.049
Time spent on developing suitable model	3.64	1.005	14	0.000
Unjustifiable benefits	3.62	1.028	15	0.000

4. Discussion

The results of this study indicate that significant aspects mainly related to the types of data formats used in the construction business, the degree of expertise, and the opinion of professionals regarding machine learning techniques. According to Bilal et al., (2016) data in the construction industry come in a variety of formats and frequently need to be cleaned. This may have a significant impact on how machine learning is used and implemented, which in turn affects adoption. This is because experts who are unfamiliar with ML approaches won't know which data to utilize them on. Which will then have an impact on how others perceive them, and which can affect how extensively they are adopted in the building sector. It's crucial to keep in mind that for any organization at any given time, the trade-off analysis is not between implementing or not implementing a new technology or process (as in the case of ML techniques); rather, it is between implementing it right away or delaying that decision until a later time (Rana et al., 2014). This distinction is crucial since adoption is influenced by organizational and environmental factors as well as direct advantages and limitations of a particular technology at a given period. The survey also showed that enterprises now have access to a sizable and continually expanding amount of data that can be used to improve processes, goods, and services by providing helpful insights (Ranjan & Foropon, 2021). Machine learning techniques have a great potential to help businesses with this. The use of these strategies in industry is now far from ideal, despite evidence of their value in academia and the availability of instruments. This study shows that in order to hasten the adoption of ML-based approaches in industry, it is necessary to improve our comprehension of the information requirements of industry in this area. According to Zhang et al., (2021), a technology acceptance model offers a practical method to achieve this goal. Labor-intensive industries like construction run counter to modern trends like an aging population. The greatest obstacles to the construction industry's profitability are labor cost losses and a shortage of on-site personnel as a result of the demographic dividend's progressive absence and rising labor expenses. Using machine learning and other artificial intelligence technologies to increase the level of automation in the construction industry is an unavoidable development given these circumstances (Kuang et al., 2021). While evaluating the use of machine learning in construction, there are some key factors to take into account. First off, since the technology in this area is already relatively advanced and the vision-related component is the most commonly used component in the construction sector, the field of computer vision will advance quickly (Ding et al., 2022). Due to the consistent nature of the tasks that object detection and action recognition models are trained for, they typically perform well in subsequent projects. Deep learning will become more significant as safety issues in construction or automatic detection become more prevalent; shallow learning will still be used for processing before deep learning is used. Second, data is essential for machine learning applications in the construction industry (Vadyala et al., 2022). Establishing a public data source for the building sector is crucial. A construction-related dataset could have a similar impact on research in the field of construction automation as the general-purpose dataset ImageNet, which is similar in design. Construction stakeholders can concentrate more on deep learning algorithms with these kinds of open data sets.

5. Conclusions

The first conference on the topic of machine learning took place in 1956, so the field of study is hardly new. Nonetheless, it has gained greater attention in the last ten years and has a significant impact on the advancement of automated technologies in the built environment. However, due to factors including knowledge level, ambiguity about possible advantages, and dataset features outlined in the study, implementation has only had a limited amount of success. To power the insights that may be gleaned from ML, a large amount of data must be present, and over the last few years, this amount of data has increased dramatically. Throughout the past few years, there has been significant investment in construction technology. A significant percentage of that expenditure was used to digitize various processes involved in the construction cycle. Building information modeling (BIM) models have altered how structures are planned, project management, issue management, and operations management processes have all moved to the cloud and are becoming more sensorised and automated. The utility of ML-based applications will increase with the availability of data in the construction industry. It is possible to automatically rank topics using ML, specifically construction language analysis. The algorithms are able to comprehend and forecast complex situations, such as whether a problem could lead to an intrusion if it is not resolved. It is advised that ML approaches be adopted because they will be crucial to solving important environmental and physical modeling issues in the built environment in the future of scientific modeling.

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An Overview of Human Resource Management Practices in the Nigerian Construction Industry

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Abstract: Pursuant to the adoption of practices utilized in workplaces from other countries; and the dearth of study that adequately investigate human resource management practices (HRMPs) that enhanced the performance and productivity of human resources (HRs) and construction professionals (CPs) in the Nigerian construction industry, this research examined the general overview of the Nigerian construction industry HRMPs. A review of the literature was employed and sourced from published journals and conference articles from Web of Science and Scopus databases. The review's outcome revealed no HRMPs model developed for the Nigerian construction industry, no standalone national competition policy or law on HRM-related issues, and no independent authority in Nigeria in charge of implementing HRM laws or policies. Further, local content law is absent for the Nigerian construction industry to develop and promote HR participation in the industry. The review findings signified the importance of a developed HRMP model and policies recommended for promoting HRM practices in the Nigerian construction industry. The outcome of this review will be of immense benefit to HRs and CPs for improved performance and productivity in the Nigerian construction industry and Africa as a continent.

Keywords: HRMPs, HRM policies, HRM evolution, Construction industry, Nigeria

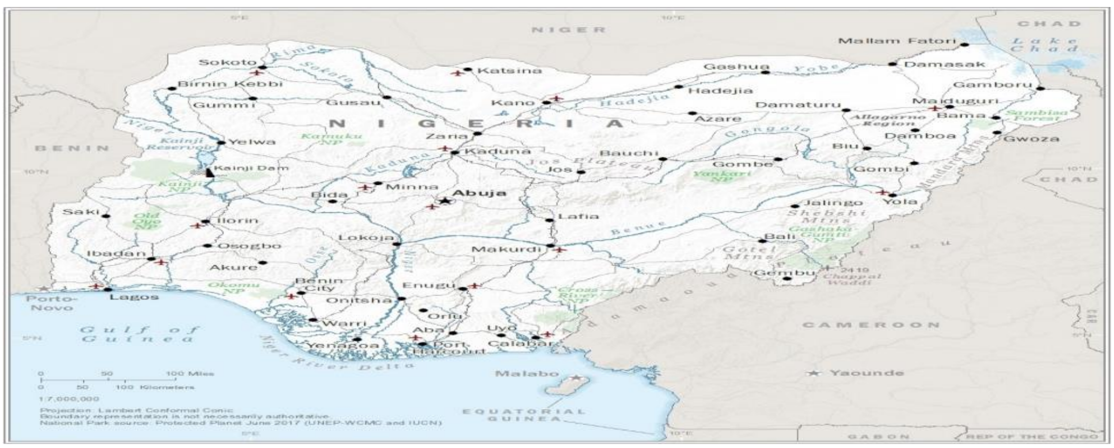
1. Introduction

Human resource management practice is fast becoming a strategy utilized by every organisation towards gaining a competitive edge. Agreeably, HRMPs have been defined as activities used in attracting, developing, motivating, and retaining employees towards effective utilization and survival of HRs and organisational achievement (Gope, Elia & Passiante, 2018). Accordingly, Placide, Gwaya and Wanyona (2019) defined HRMPs as a means through which workers' skills, attitudes, and behaviour are influenced and shaped to ensure work is done and achieve organisational goals and objectives. Different authors have viewed HRMPs; they all centered on how the most valued assets- the people are managed to realize its goals and objectives.

The construction industry is a labor-intensive sector that contributes to the economy of a country. According to Durdyev and Ismail (2012), the industry is large, responsive, and it has roles and linkages through the workforce. Assertively, Windapo (2016) stated that the workforce is responsible for the activities within the construction industry. Conversely, Chieng, Arokiasamy and Kassim (2019) opined that since employees' expertise is an essential ingredient through which competitive advantage is achieved in a rapidly expanding global economy, a construction organisation needs to implement effective HRMPs that make the best use its employees. However, in Nigeria today, there is a lack of studies on HRM practices in the Nigerian construction industry that assessed the indigenous construction firm's HRMPs. This review carried out a general overview of HRMPs in the Nigerian construction industry, intending to recommend areas where HRMPs can be promoted in the construction industry. In achieving this stated aim, the overview of the Nigerian construction industry; the evolution of HRM policies in Nigeria; an overview of HRMPs studies, and HRM policy framework in employment-related issues in the Nigerian construction industry (NCI) were examined.

2. A brief background of Nigeria

Nigeria is situated in the Western part of Sub-Saharan Africa, bordering the Gulf of Guinea, between Benin and Cameroon (Central Intelligence Agency, CIA, 2017). Figure 1 shows the map of Nigeria indicating her surrounding neighbouring countries with international borders, major cities, among others, with Abuja the national capital. Nigeria is made up of several tribes with over two hundred and fifty ethnic groups, but the three major tribes are Yoruba, Hausa, and Igbo. Great Britain colonized the country until it gained independence in 1960. Furthermore, it is ranked 21st largest economy in nominal GDP with a real GDP growth rate as estimated in 2017 to be 0.8% of the GDP. The country covers a total area of 923,768sq km, about six times the size of Georgia but slightly twice the California size. Its estimated population in July 2021 is 219,463,862. The country is well endowed with natural resources such as natural gas, tin, iron ore, niobium, coal, limestone, arable land, zinc, lead, and petroleum which the country depends on as its main source of revenues and foreign exchange. Due to economic crises, Nigeria's economy has been driven by agriculture, telecommunications, and services (CIA, 2017). However, the country is faced with other notable challenges but not limited to the inadequacy of power supply, lack of infrastructure, insecurity, inefficient property registration systems, and delays in legislative reforms (CIA, 2017). Currently, Nigeria is a lower-middle-income country (World Bank, 2017).



Map of Nigeria
Source: The World Factbook (2021)

3. Overview of the Nigerian construction industry

The NCI, significant in its way, shares similar characteristics with other developing countries' construction sectors. These characteristics may include low skills levels and productivity, nature of construction processes, time and cost overruns, risks, high labour turnover, interference at the selection stage, amongst others resulting from complex social-cultural, contextual, and structural issues prevailing in other developing countries (Dania, Larsen & Ewart, 2014; Ameh & Daniel, 2017; Daniel,Oshineye & Oshodi, 2018). The construction industry is dominated by main or specialist contractors, private or public clients, mostly the owner and financiers of the projects, and consultants who ensure project delivery within the right budget, time, and specifications. According to Dania, Larsen and Yao (2013), it ranges from small, medium and large enterprises to technically competent multinational construction firms. Owning to the lack of capacity of most small enterprises to undertake massive civil engineering construction projects, multinational construction firms are evident in the Nigerian construction organisation and other developing countries.

In construction organisation, there is provision for both the standard forms of contract claims and advance payment. Amucheazi and Nwandem (2020) informed that the standard forms of contract claims are provided to guide and inform contractors, employers, and arbitrators on what should be known before making any claims. These standards are: for road works (The Federal Ministry of Works Standard Conditions of Contract); for building (The

Federal Ministry of Works and Housing Standard) as well as the FIDIC (Federation Internationale Des Ingenieurs-Conseil) Red Book. Accordingly, Aje and Adedokun (2018) highlighted standard forms of contracts for advance payment in accordance with the Construction Industry Development Board (CIDB) in meeting the principles of modern contracting. These include FIDIC; General Conditions of Contract for Construction Work; New Engineering Contract known as Engineering and Construction Contract, and The Joint Building Contracts Committee. As part of the contract, no additional payment is made once the mobilization fee had been paid to contractors unless a performance certificate is raised.

The government of Nigeria is regarded as the biggest client because majorly it finances developmental projects in the country (Idoro & Okun, 2009). Most government-funded projects are managed by the Nigerian MDAs (ministries, departments, and agencies). Based on the government's interest, the Federal Ministry of Works and Housing (FMWH) is responsible for government project implementation and management in Nigeria (Idoro & Okun, 2009). Subsequently, departments/units have been established at the state level for similar purposes, such as the ministry of works and infrastructures of FMWH and private firms. To ensure fairness and frank award of government/public projects, a regulatory body named the Bureau of Public Procurement Act 2007 was implemented (Dim & Ezeabasili, 2015). The Act was established for its effective pre-tendering and tendering processes, project management, and contract regulations.

3.1 The importance of the Nigerian construction industry

Based on the literature reviewed, the activities of the construction industry are the same as indigenous firms' activities. Accordingly, Waziri, Mustapha and Idris (2017) revealed that the NCI comprises small indigenous firms. Invariably, the significance of the construction industry is the same as that of construction firms. The construction industry plays a vital role by improving the infrastructure needed for socio-economic development (Dania et al., 2013). The CI is also an active sector that provides the physical needs of the diverse millions of people. These infrastructures include but are not limited to good roads, health and educational facilities (buildings), and economic infrastructure (bridge) (Dania et al., 2014; Oke, Ogungbile, Oyewole & Tengan, 2016). The construction industry's contribution to the GDP has been extensively reported (Waziri et al., 2017; Osuizugbo, 2020). Furthermore, Waziri et al. (2017) reported that the sector employs over 5% of the entire country's labour force. This is in line with Ofori (2012) study that the construction industry employs about 10% of the working population in all countries. The construction industry is also known for affecting other sectors of the economy for its services and products (Osuizugbo, 2020). For instance, the construction industry depends on the Nigerian cement industry for its products (Moses, Simon, Olusegun & Mubarak, 2017; Ojo, Yusuf & Aremu, 2020). Furthermore, Ojo et al. (2020) revealed an estimated value of 4.0 percent of the cement sector's Nigerian construction consumption output. A trend outlook of cement demand in Nigeria (Akinyoade & Uche, 2018) shows an increase in cement production, an indication of growth in the manufacturing industry due to the construction sector demand. Notably, the government is the key player in the construction business in the NCI. To achieve construction industry potentials, priority should be given to HR in promoting growth and development.

3.2 Challenges of the Nigerian construction industry

As emphasized earlier, construction industries are supported by the Nigerian economy, which extends to other sectors. Despite this, the industry is overwhelmed with several challenges. These challenges in the Nigerian construction industry are classified and discussed under three groups: project implementation, management and performance challenges, industrial challenges, and economic challenges.

Project implementation, management, and performance challenges: In project implementation, management and performance varied challenges are encountered, which are human-related. Okoye, Ngwu and Ugochukwu (2015) reviewed the literature regarding management challenges facing construction practice in Nigeria. The study revealed top challenges such as scheduling (time), quality, cost, and safety as management challenges facing the construction industry. Waziri et al. (2017) also revealed factors affecting the adoption of IT usage in the NCI, which has made organisations lag behind compared to their counterparts in other developing countries regarding acceptance, usage, and adoption. These factors include high-level resistance to acceptance and unwillingness to invest because of the country's economic situation, and most of the partners are not into e-business. Osuizugbo (2020) revealed challenges facing building production management (BPM) in Nigerian construction firms. These include BPM unproductiveness, non-existence of buildability and maintainability analysis, lack of professionalism, and unauthorized practices. Idoro and Okun (2009) evaluated the time-overrun related challenges in Nigerian federal government projects, which need urgent attention to reduce delays in projects caused by project team members. They revealed the government as a major contributor to time-overrun as perceived by project leaders, followed by the government's main contractors and officials. Similarly, Mujaddadi and Daniel (2020) identified risks such as financial, construction, environmental, and design risk as challenges involved in construction work during the project life cycle, leading to financial loss and project stoppage. Furthermore, poor construction project performance has been a serious concern to the construction industry (Oke et al., 2016). The authors identified and grouped factors affecting project performance under four groups: cost, productivity, time, and quality. However, the study revealed that the design cost of the project, complexity of the project, unavailability of resources, and quality of equipment and raw materials are factors promoting poor project performance in the NCI. Therefore, the challenges of poor project performance are attributed to a lack of collaboration among professionals (HR) involved in carrying out construction works. As mentioned earlier, Nigeria is faced with notable challenges such as a lack of infrastructure. Lack of infrastructure could be attributed to the NCI failure and abandonment. Accordingly, Dim and Ezeabasili (2015) reported that non-adoption and implementation of modern procurement strategy result in abandonment and construction projects' failure. These are attributed to poor pre-tendering and tendering processes, poor integration and management of the supply chain, political interference and inference, and corruption among procurement officers.

Industrial challenges: As mentioned earlier, government projects are implemented and managed by an established body of the federal government. Still, the construction industry activities are not well coordinated. Amade (2012) laments the need for established partnering through collaborative approaches among project team partners in the NCI. The author points at factors that hinder partnering in construction project delivery: corruption, additional costs, career prospects, and loss of confidentiality. Scholars, including Dodo (2014); Agbede, Manu, Agbade and Mahamadu (2016), have described the non-existence of regulatory bodies in charge of health and safety plans and practices as a challenge to the NCI. This has posed severe threats to workers and non-workers due to reports on accidents occurrence during construction activities. The industry's lack of capacity in terms of financial problems has hindered the participation of construction firms in large-scale construction activities and limited their performance and contribution to economic development (Ugochukwu & Onyekwena, 2014; Ali, Awad, & Abdulsalam, 2019). Further, Frank, Rong, Batool, Paul and Tungom (2017) lament the low level of effective technology transfer in the Nigerian construction sector. The authors acknowledge that technology transfer brings effective performance among local talents and skills needed for industry expansion. However, the high rate of corruption cases and acquiring raw materials from other countries, amongst others, hindered the transfer of technology in the NCI.

Economic challenges: Presently, Nigeria's economy is expressing recession which impacts financial pressures on all sectors of the economy. Due to this, activities of the construction industry have drastically reduced, which resulted in staff downsizing, non-recruitment of employees, folding-up due to inability to adapt to the economic situation. Further to this, for most firms to survive, contractors opt for reduced tender pricing, cost control, improved site management procedures, effective management relation with clients, and business diversification (Olowa, Amuda & Adebiyi, 2018). However, despite the NCI challenges, the economic viability and contribution of the CI to the Nigerian economy are vital.

4. Overview of HRMPs studies in the Nigerian construction industry

Though HRM has been recognized in the NCI (Ameh & Daniel, 2017), however, dearth of studies assess indigenous construction industry HRMPs, determine the attributes of HRMPs in the construction industry, or develop models that enhance construction industry HR performance and productivity in Nigeria. This has left the indigenous firms in Nigeria to adopt practices utilized in workplaces from their counterparts. Specifically, this has hampered the performance and productivity of the NCI (Fajana, Owoeye, Elegbede & Gbajumo-Sheriff, 2011).

HRMP studies in the NCI have focused on challenges facing HRMPs. For example, Ameh and Daniel (2017) identified globally mobile talent competition, high experience labour force avoidance, reduction in cost per hire, right person recruitment, right candidate occupying vacancies advertised within a firm, attracting high reputable staff from other firms. In addition, Yaro (2014) attributed the recruitment challenges, an element of HRMPs in the public service, including construction firms, to be political office holder's interference in the recruitment process that involves sentiments. In other related studies, Ifediora et al. (2020) argued that HRMPs in Nigeria are affected by inappropriate recruitment and selection practices and the non-availability of workers' involvement in project implementation, contractor's wrong appointment, lack of health, safety and welfare programs. Further, Chukwuemeka (2006:46) revealed challenges facing HRM practices as government policies, and legislation that deals with minimum wages, federal character involvement in the recruitment and selection process. Furthermore, Orga and Ogbo (2012) informed that challenges facing HRMPs include inconsistent labour union law, conflict and high turnover, overload of information, a mix of the workforce, workforce changing demand, and employers changing demand.

In addition, Chukuma (2015) revealed poor productivity improvement, implementation of quota system in employment as HRMPs challenges in Nigeria. Further, Ajayi, Akinsiku and Salami (2019) highlighted challenges of HRMPs in Nigeria: lack of business strategy, organizational structure, organisational size, organisational mission/vision, priorities of managers, and lack of commendation on work done. Thus, whereas much is known of the challenges of HRMPs in the NCI, there is a dearth of studies that develop a model on HRMPs to enhance HRs indigenous construction firm's performance and productivity. Hence Ameh and Daniel (2017) opined that gaps in HRMPs studies due to lack of research could be attributed to the non-usage of such practices in the NCI. So, based on this affirmation, there is a need to address the gap in knowledge by developing a HRMPs model for the NCI. Further, though the challenges facing HRMPs appear to be known, few studies seek to determine which of the obstacles critically face the NCI. Against this backdrop, there is a need to establish the critical challenges confronting HRMPs implementation in the NCI.

5. Evolution of HRM policies in Nigeria

After Nigeria gained independence on the 1st of October 1960, several economic and developmental reforms were undertaken by the civilian governments of the first republic, successive military, and the civilian of the fourth republic. These reforms bring about development and the potential for continuous growth in many sectors of the economy. One of the major economic reforms after independence is labour laws (Obodo, 2017). Before independence, Nigeria's early labour laws were dictated; this resulted in the agonizing and traumatic experience of the workforce because of an imbalance in power of both the employer and the employee (Obodo, 2017). After independence, the labour laws were enacted relating to employment contract improvement on Nigerian workers' welfare and economic condition. These laws are workers' work conditions, safety and health at the workplace, wages and salary, trade unions, trade disputes, conciliation, and arbitration. Accordingly, the author informs that the labour law enacted helps regulate gross defects on HRM activities such as contract of employment in Nigeria, conditions of work, the safety of workers at the workplace, right to wage, hours of work, settlements of disputes, termination of contract and pension. HRM laws and policies draw their sources from the provisions of the 1999 constitution of the Federal Republic of Nigeria. The constitution enjoins the parliament under Section 16(1)b to enact relevant laws, and in consultation with the executive arms of government, formulate and ratify laws to promote the welfare, freedom, happiness of every citizen in the society that is healthy to Nigerian economy (Federal Republic of Nigeria, 1999).

Currently, there is no standalone national law or policy on HRM that regulates the management of infrastructures and workers in the construction industry and other national assets in Nigeria (Fajana et al., 2012; Obodo, 2017). In support of this, Nnedinma, Boniface and Keith (2014) concluded that the failed occupational safety and health system (OSH) in the NiCI is due to the non-availability of statutory regulations and provision of OSH. However, there are ministries, departments, and agencies (MDAs) that monitor and carry out infrastructural activities that involve HRs on the national asset of the Nigerian government. The MDAs include the Federal Ministry of Works and Housing, the Federal Road Maintenance Agency (FERMA), and the National Emergency Management Agency (NEMA), amongst others (Idoro & Okun, 2009; Odediran, Opatunji & Eghenure, 2012). Conversely, the Nigerian government had adopted and applied various developmental plans since her independence: the 1st National Development Plan (1962-1968); the 2nd National Development Plan (1970-1974); the 3rd National Development Plan (1975-1980), and the 4th National Development Plan, which never came through (Lawal & Oluwatoyin, 2011; Emmanuel, 2019). There was another long-term developmental plan between the early 1990 and 1998 due to a continuous search for optimal strategy (Emmanuel, 2019). However, different plans were introduced by the Federal Government towards upgrading the existing basic infrastructures in the country between 2003 and 2019. Such policies include but not limited to the structural adjustment programme (SAP), Vision 2010, the National Economic Empowerment and Development Strategy (NEEDS) 2003-2007, Vision 20: 2020, Economic Recovery and Growth Plan (ERGP) which is of recent till date (2017) (Marcellus, 2009; Lawal & Oluwatoyin, 2011; Emmanuel, 2019). All these policies and plans are put in place to map out strategies that will enhance developmental advancement in Nigeria.

However, there was a notable step in developing HRM framework in the area of training introduced by the government (Clardy, 2003). The idea that Nigeria does not have an "emotionally intelligent HR" brought about the HRM framework (Drigas & Papoutsi, 2019). Equally, institutions such as the Nigeria Society of Engineers (NSE), Council for the Regulation of Engineering in Nigeria (COREN), Charted Institute of Building (CIOB), Council of Registered Builders of Nigeria (CORBON), and Nigeria Institute of Civil Engineers (NICE) amongst others have constantly been agitating for a developed HRM framework in Nigeria for HRs in government construction sectors.

6. HRM policy and legal framework in employment-related issues in the Nigerian construction industry

The Labour Act, Ch L1 Laws of Federation of Nigeria 2004, Section 91 was promulgated to govern employment-related issues principally in Nigeria between an employer and an employee (The Constitution of the Federal Republic of Nigeria, 1999).

However, the Labour Act, established by Labour Act Chapter L1 of Labour Decree No 21 of 19974 in 1999, was created to provide comprehensive legislation on work conditions and employment conditions. Fundamentally, it was designed to protect workers against employers' abuses in employment (Nwokpoku, Monday, Nwoba & Amaka, 2018). In relation to the general contract of employment in Nigeria, especially in the construction industry, HRM is regulated by the Nigerian Labour Act, the Nigerian Labour Ac 1974, the Nigerian Factories Act 1956, the Trade Union Ordinance of 1938, Trade Unions Act 1974 (amended 2005), Trade Disputes Act 1976 (amended 2004), Pension Act 1979 (amended 2004) (Nwokpoku et al., 2018). The Nigerian Labour Act stipulates a contract offer and acceptance, which is definite, done through the offeror to the offeree. According to section 7(1) of the Act, the employer must give terms of his/her employment to the employee within the three months of the worker's period. Further, the Nigerian Labour Ac 1974 deals with the provision of payment of wages Act 1960, enacts that wages of a worker shall be in a legal tender but if otherwise, it shall be illegal, null, and void. According to section 5(2) of the Act, an employer may deduct from his worker's wages any contributions under the provision of the consent of such worker. In addition, the Nigerian Factories Act 1956 governs the safety and health of workers at the workplace. Section 14(10) of the Act stipulates that while work is ongoing, the work environment shall not be overcrowded to avoid the risk of injury to the health of workers therein, while Section 28 of the Act state that no person shall be employed at any machine unless a worker has received sufficient training in work among others. Nonetheless, these Acts were promulgated as decrees during the military regime in Nigeria. The National Assembly revalidated the Act as Laws of the Federation of 1999. These laws help workers to agitate for their fundamental rights in an organisation.

7. Conclusion

The review assessed HRMPs in the NCI. From this study, the relevant literature reviewed about Nigeria showed that previous studies relating to HRMPs focused extensively on the challenges facing HRMPs in the Nigerian construction industry. Thus, the factors that determine HRMPs are empirically unknown. Also, there is a dearth of studies that develop models to help firms manage their HR in the construction industry. Also, Nigeria has no standalone national competition policy or law that holistically addresses HRM-related issues. However, there is Act Chapter L1, Section 91, The Labour Decree No 21 for the Protection of Workers Against Employers Abuses in Nigeria. Again, there is no independent authority in Nigeria responsible for the implementation of HRM laws or policies. Further, there is a lack of standalone local content law for the NCI to develop and promote the participation of HRs of indigenous construction firms in the industry.

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Enhancing User Experience through VR: Case of an Urban Agriculture Participatory Design Experiment

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Abstract
Virtual Reality has shown great potential when applied to the AEC industry. There are some less researched areas where VR can prove effective; among those are enhancing user experience and improving stakeholder participation. User participation in co-design of public and semi-public spaces has been advocated as a means to ensure wider community engagement and better project success. A series of different methodologies have been used to study urban agriculture. There is limited evidence of the application of VR to promote design participation in community projects and urban agriculture. With a wide range of proven capabilities and benefits, VR seems to be the next logical step to further progress community research for urban agriculture. This paper uses game engines to develop a Virtual Interaction Environment (VIE) to facilitate participation in urban agriculture beyond the existing boundaries of established methods. A critical review of literature was carried out to set the boundaries of this research, investigate the principles of participatory design and the user experience. The findings of the literature were used in combination with the outcomes of a "Map Walk" workshop with community participants to define a set of design variables to be incorporated in the design of the VR instrument for urban agriculture projects. The process of collecting the data in Map Walk, the development process of the VR experiment (the Alpha Build), the feedback loop from the VR experiment first run, the data verification and second stage of the VR experiment development (the Beta Build) and the second feedback loop are explained in this paper. The paper concludes with directions for future development in this area and for the use of VR in participatory community projects.

Keywords
Virtual Reality, Urban Agriculture, Collaborative Design, User Experience, Map Walks

1. Introduction
Research on user experience through VR is well established. Community projects have benefited from an extended attention over the recent years. Urban agriculture has a long history which dates back to early human settlements. Analogue methodologies have been developed to systematically review, document, and utilize non-expert participants' input in community projects. There is however, a substantial gap in application of VR technologies in this area.

This study was funded through a Research England participatory research fund to investigate the role VR can play in enhancing the participants' experience in community garden projects. The research built upon an existing analogue methodology known as "Map Walk"[1] developed by researchers in University of Brighton back in 2014 and used for community urban garden projects to investigate what new and advanced technologies - in this case VR technologies - can offer to such projects. A three-staged qualitative research plan was developed to observe and comprehend the analogue methodology and to best develop an exclusive digital solution based on VR technologies to complement what was otherwise difficult if not impossible to achieve through analogue methodology. The design of this study, its development process and some of the preliminary findings of it have been explained in a separate paper

[1] Map Walk is a semi-structured guided tour using exclusively created orthographic maps of urban spaces with highlighted potential areas suitable for urban agriculture interventions, followed by a focus-group style meeting to discuss and document participants' views, opinions, and reflections on urban agriculture in the context specifics of the study cases.

in this conference. Detailed data collection and more in-depth qualitative text analysis of the user data during the analogue walk and two stages of the digital walks will be presented separately later on.

This paper concentrates on the development process of the novel research instrument developed specifically for this study based on the study of existing methodology and feedback received from the research participants. The research instrument was designed as an VR technology interactive digital walk through selected urban sites in Brighton city center, in South East UK. The development of the digital research instrument benefited from a two-stage development process known as the Alpha and the Beta Builds. The experiment was designed to help fulfill some of the objectives which were set out in this study including: 1) to develop an custom-built, customizable, easy-to-use, useful and flexible research instrument to facilitate co-participation; 2) to verify the instrument through user perception and attitudes towards the use of VR technology; 3) to establish areas for improvement; 4) to improve the VR experiment, rerun the user experience.

In addition to the above objectives of this study, this paper will also partially contribute to the last objective of the study that is: 5) to highlight the contribution and lay the foundation for future research in this area.

We start with a summary of the critical literature review to be used in conjunction with the goals set out to be achieved through the analogue map walks and the needs, wants and expectations of the participants which were collected through a focus group after the map walk experience to best devise the VR walks. It was deemed of paramount importance to keep the flexibility of what could have been offered through the Virtual Walks at maximum to be able to attend to the widest range of expectations expressed by the participants. Therefore, a generic game engine, although imposing a higher level of challenge, was the preferred route as opposed to an off-the-shelf application which would have been much easier to utilize but would have put more limitations on the width, breadth and depth of what could have been offered. An additional challenge was that many if not all of the research informants were from a background with very limited experience in VR beyond some limited gaming experience and most with no experience of or expertise in the Built Environment. Many of the participants however had some level of prior exposure to community or participatory projects which proved to be extremely helpful in the process of development of this study.

The Unity game engine was the engine of choice for its most relevant and direct benefits to this study above all the interface with GitHub which facilitated collaboration between developers in the development process of the virtual walks.

This paper will explain the development process of the VR experiment for virtual urban walks in depth with a special focus on the feeding back and forward process between the participants' attitudes towards and perceptions of VR and how those collected feedbacks were used to develop and subsequently to enhance the VR experiment during the two-staged process of development.

2. Literature Review

2.1 Urban Agriculture

Urban agriculture was mainly addressing Africa, Asia, and Latin America – the Global South – when first utilized by the UNDP in 1996 (Smit et al., 1996). Ever since, it has permeated into developed economies such as the United States (Balmer et al., 2005, McClintock, 2008), the United Kingdom (Viljoen et al., 2005, Cullen, 2008, Tomkins, 2014), Canada (Kaethler, 2006), Switzerland (Jahrl et al., 2021), France and Germany (Kirby et al., 2021, Pölling et al., 2016) and Japan (Yuan et al., 2022). Motivations for, and social impacts of different types of urban agriculture have been studied using case studies in Europe and the States and Europe (Kirby et al., 2021). Jahrl et al. (2021) have used Knoepfel et al.'s Political-administrative programme (PAP) (2007) to analyze city policies on food gardening with reference to urban sustainability.

It has been argued that although distinction can be drawn between urban agriculture and community gardens (and community food gardens as an extended concept), there could be benefits across the different concepts and that they have been used interchangeably (Tomkins, 2014). Nonetheless, agricultural activities in cities are as old as human settlements (Reculeau, 2017). Agricultural activities have swayed back and forth between inner-city spaces and city fringes and suburbia as a result of industrialization (Steel, 2013) and revival of urban horticulture (Appel and Spitthöver, 2011, Keshavarz et al., 2016).

Referring to the works of Dubová and Macháč (2019), Olivier and Heinecken (2017), Reynolds and Cohen (2016), Kirby et al. (2021) argue that food production in urban spaces offer four social benefits namely health and wellbeing, economic opportunities, social cohesion, and education. While working classes have used it as a way of enhancing food security, the upper classes turned to it as a means of self-realization, expression of individuality and/or a healthy lifestyle (Appel and Spitthöver, 2011). CPULs (Continuous Productive Urban Landscapes) have been proposed as an environment "productive in economical, sociological and environmental terms" (Viljoen et al., 2005). The value of urban agriculture is believed to extend beyond mere profitability and include social, health and well-being, disaster risk reduction, and other environmental perspectives (Yuan et al., 2022). Kettle (2014) have looked into motivations for investing in allotment gardening in city of Dublin and community gardening has been studied as a means of place-making in social housing (Truong et al., 2022).

2.2 User Participation and VR User Experience

Virtual environments can be alternatives to real environments for user experience studies, when a high presence is achieved (Busch et al., 2014). User experience is a determining factor in user participation for XR (eXtended Reality) technologies. User experience in immersive environments has been measured through different aspects or concepts directly or indirectly associated with it including engagement (Boyle et al., 2012) which, in a web application context, consists of cognitive, emotional and behavioral engagement according to Attfield et al. (2011), presence (Hein et al., 2018, Cummings and Bailenson, 2016) defined as "the propensity of people to respond to virtually generated sensory data as if they were real" (Slater et al., 2009, p.194), and enjoyment (Dey et al., 2018). It has been suggested that although VR and AR user experience research has recently benefited from an ever-growing level of attention, a direct comparison between different immersive technologies' user experiences is few and far between (Verhulst et al., 2021). Researchers who have carried out comparative studies between AR and VR in the AEC industry have suggested that 3D modeling is not a complication which can easily be ignored or avoided, VR can facilitate an earlier detection of problems at design stages (significantly more than AR can do), VR is capable of reducing the reliance on cognitive functions for the tasks (again significantly more than AR can do), and recorded higher level of feeling dizziness and motion sickness in VR than AR while AR was reported less fit-for-purpose than VR in their then state of development (Piroozfar et al., 2017).

3. Research Design and Methodology

This paper focuses on the development of the research instrument which was used for data collection and analysis in two stages of a study carried out to gauge the community stakeholder groups' perception of, and attitudes towards, the use of VR technology for urban agriculture community projects. The design of the study and preliminary findings have been presented in a separate paper.

The development of the VR-technology research instrument was carried out following an in-depth literature review of urban agriculture, user participation and VR user experience, VR for participatory design and map walks for urban agriculture. We used the map walk methodology developed by Tomkins et al. (2014) and applied to several projects before, to walk the participants in the center of City of Brighton and Hove, in South East England, UK to visit a series of potential sites for urban community gardening, to discuss possibilities, potentials and restrictions around those sites and listen to concerns of different stakeholder groups' representatives who participated in the walk. This followed by a focus group discussion in the Community Kitchen Center in Brighton. The participants (N=16) were divided into smaller groups of 4-5 and participated in a semi-structured discussion. Each group was led by a member of the research team. The findings were collected and together with the findings of the literature review and in consultation with the Map Walk team were used to develop the main research instrument of this study in the form of a VR experiment, developed exclusively for this study using Unity game engine. The development of VR was conducted in two stages each followed by a data collection/analysis exercise; these are called the Alpha Build and the Beta Build. The Alpha Build was used as a testbed whose data collection/analysis outcomes were utilized for verification and improvement of the application and to develop the Beta Build. Together with the in-depth qualitative analysis of the participants' feedback in all three stages of this study, the final prototype of the VR application will be used to further develop research applications to investigate areas that were pointed out by participants in different stages of this study. This paper explains, in detail, the process of the development and improvement of this application during the Alpha and Beta Build stages.

4. VR Experiment Development (Alpha Build)

4.1. Spawn in place

In order to allow users to visualize the elements of urban agriculture in context of the given environment, a 'spawn in place' system was developed. This system allowed users to add and remove urban agriculture elements during runtime. In order to enable this, two distinct tools were developed, a spawn tool and a delete tool. The spawn tool was separated into three statuses; inactive, active and placeable, and active and unplaceable. When inactive, the tool was simply disabled, meaning that the tool neither rendered or functioned when an input was passed. This status was controlled via the UI menu, whereas the tool only became active when the spawn object menu was also active. The spawn tool utilized raycasting, in which a ray would shoot from the user's controller to the colliders within the virtual environment. At the point that the raycast hits the ‘Ground’ collider, a hologram reticle was presented, acting as a visual cue for the participant to understand the rotation and proportions of the object they are spawning. In order to determine the status of placeable/unplaceable, the collider attached to the hologram was utilized to detect when this may be clashing with other objects within the scene. In the case that the hologram collides with a pre-existing object, the spawn tool would render red and any input passed would not invoke the spawn method. Once clear of the object, this would render green and the spawn method can be invoked when an input is passed. The spawn in place tool also needed functionality to be able to remove elements currently in the scene. Utilizing similar principles derived from the spawn tool, raycasting was employed to detect collisions with spawned object colliders. In the instance that a collision is detected and an input passed, a delete method would run, utilizing Unity’s built in ‘Destroy()’ function. This however did not work as expected; the ‘destroy’ function required a transform (XYZ Position) to be passed in order to find the object to remove. However, as colliders would operate on local positions as opposed to world positions, the delete method returned a transform at identity (0,0,0). Subsequently, when one object was ‘deleted’, all objects from the scene were removed at the same time, as they all shared the same local position. To overcome this issue, the raycast instead detected the collision before iterating through a list of the currently spawned objects using the Unity ‘FindWithTag()’ function, allowing the tool to determine the correct object to delete. This was not ideal for the application as the function consumes a great deal of performance, however due to the limited number of objects that would feasibly spawn in the scene, this was opted for as an immediate solution.

4.2. OSM Modelling

In order to provide context to the site, a 3D model of the city was desirable to include within the VR application. To facilitate the development of the 3D city, an open source tool called ‘Blender OSM’ was utilized. This tool allowed the generation of 3D models within a given area; utilizing open source data, elements such as building heights, building footprint, road paths, terrain levels and other geographical features were amalgamated to form a comprehensive 3D model within the modeling software Blender. In order to efficiently represent the map generated by the research team, some edits were made to the generated model. The blender software aided in this as it provided the flexibility to edit any aspect of the imported data from the OSM plugin. In turn the study area was highlighted in orange so that context could be derived from the surrounding buildings shown in white when viewed in context with the study map. This model was subsequently exported and imported into the game engine software.

4.3. Lighting & Baking

During the development of the alpha build, focus was placed on achieving the correct shape and form of the 3D models, and subsequently the lighting was implemented towards the end of the build. In turn, some visual artifacts created by poor UV map exports from Sketchup meant that many of the objects were patchy, with significant color bleeding. Due to the timescales for this build, this was not corrected in time, however, it was important to include these artifacts during the feedback stage so that they could be highlighted and addressed.

4.4. Audio

Pre-recorded audio sound effect files were obtained and modified using audio editing software (Adobe Audition etc.) to achieve the desired effect. Inside the Unity game engine, these sounds are delivered through an 'Audio Source', to be applied for diegetic or non-diegetic purposes. This would be determined by how the audio is enabled and the variables applied. Diegetic audio was implemented through a location (world position) based approach, whereby 'loop' and 'on awake' variables ensure the audio remained a constant from the beginning of the scene - these included sounds such as bird, car and wind noises. Non-diegetic audio was implemented through a trigger-based mechanism within the user interface. These included short duration sound effects in response to user input (i.e. User Interface buttons).

4.5. LiDAR

During development a mobile phone with LiDAR camera with scanning applications were used to obtain point-cloud information of the associated real-world spaces. This information could then be exported into various point cloud formats (e.g. .PLY) and imported into 3D modeling software (SketchUp, Blender etc.). The large file sizes associated with point-cloud scans are not suitable for use in VR development environments due to computing load. As such, the scanned point-cloud was used as reference for modeling, as opposed to direct use, and exported to Unity game engine.

4.6. Locomotion and Scene Transitions

There was a need to develop a VR-based input system for locomotion to allow user navigation around 3D scenes. In particular, it was decided that teleportation-based locomotion (non-continuous motion) would be implemented rather than motion-based or any other type of locomotion, so as to avoid motion sickness and better ease of use. Locomotion capability was initiated through use of Unity’s XR Interaction Toolkit which supports OpenXR controller input (for wider compatibility across headsets). This provided the framework for interaction via components to build the locomotion system. Locomotion was built through the following: An 'XR Origin' representing the user's position within the 3D space; A Locomotion System script which controls access to the XR Origin (i.e. which Locomotion Provider controls the rig); And Locomotion Providers which physically move the XR Origin and consist of: Teleportation Provider, Snap Turn Provider, Continuous Turn Provider, Continuous Move Provider. As previously mentioned, continuous forms of movement were excluded from this application. The system was implemented by first setting up the XR Origin and applying input actions (via the Input Action Manager) to the headset controls, the default XRI Input Actions were used as these serve a good universal standard across headset controls. A Locomotion System and Teleportation Provider were added to the XR Origin component, along with a Snap Turn Provider with controller bindings set to left and right hand movements. To provide teleportation functionality, Teleportation Areas were set up to serve as collider planes for the XR Ray Interactor, of which is assigned to Left and Right Hand Controller game objects. The resulting line from the raycast was modified for aesthetic purposes by adding a 'XR Interactor Line Visual', allowing variables to adjust appearance and behavior. This also required the 'Line Renderer' component to function. Regarding scene transitions, a scene loader script was created which utilized 'on click' event commands linked with user interface buttons, the event tells the application to load a particular scene, the result of which would be that the user could navigate to different scenes once a UI button has been activated (pressed).

4.7. Modeling and UV Mapping

The process for developing 3D models, where not using pre-constructed assets, was done so within both SketchUp and Blender, the decision of which to use depending on the modeling requirements. Simpler 3D models were created within SketchUp which allows for rapid creation of flat-surfaced geometry such as buildings, furniture and some landscapes which do not require the level of detail of more complex objects which are otherwise best created within Blender; in some cases SketchUp objects were exported to blender to add further complexity and for UV mapping. Conversely, Blender offers advanced modeling tools, such as subdivision surfaces, NURBS, curve tools, Boolean operations, as well as custom shaders, materials and functionality.

4.8. User Interface

The UI system developed included elements such as buttons, text fields, drop-down menus, sliders, and other interactive elements allowing the user to interact with the software via activation of scripts or game engine components. These elements were hosted on UI pages, or 'Canvas' component, and triggered via VR control input with the left trigger button. UI pages were grouped under a parent 'menu' and, for ease-of-use and accessibility, tied to the left-hand control mechanism. The style of the UI design followed principles of skeuomorphism and was intended to reflect that of a binder, whereby information is contained within tabulated containers sorted by category.

5. Experiment Feedback (Alpha Build)

5.1. Spawn in place

The feedback received from the spawn in place system tended to focus on the rigidity and linearity of the spawning system. Comments were particularly related to polytunnels and planters, suggesting that these should be able to snap together and offer different module styles, including instances that can be stretched/extended. As well as snapping object to object, the participants also proposed that the objects snap to a fixed world grid, allowing for better space planning while also providing a clear visual indication of where the objects could be spawned. To address the principles of urban agriculture, participants also suggested that the tool be developed further to be able to spawn different types of plants/vegetation within the spawnable planters/polytunnels, as well as single entities on the ground. Furthermore, if the user was able to design their own spawnable objects before placing them, this allowed for a deeper level of communication and ideas can be shared more forthcomingly. Participants provided little feedback on the delete tool, suggesting that this was robust in fulfilling its purpose, however, users did enquire as to whether the delete tool could be used to remove elements already in the environment such as paths and buildings, otherwise referred to as terrain editing.

5.2. OSM Model

The feedback received on the 3D city model stemmed from providing geo-referenced context. Participants felt that the city model provided little context to streets, landmark features, orientation and site location when viewed in isolation, i.e. separate from the map presented digitally behind it. Users suggested highlighting features using tags/colors to be able to derive context to the site. In contrast to this, participants expressed that the city model helped provide a macro view of the project and helped guide them into the experience. This was also true of the 1:50 model (not developed using OSM).

5.3. Drawing Tool

Following the demonstration of the alpha build, users had expressed the need to develop their own 3D objects, alluding to different sizes of the currently implemented objects as well as further object types, such as plants and trees. Users also wished to manipulate the existing site, such as changing site levels. Due to time and feasible UI limitations, an interim solution was developed to address this concern. The solution formed two approaches. Firstly, additional items were added to the 'place object' list and of these additional items, some took form of varying sizes of already implemented objects. Secondly, a drawing tool that allowed users to sketch in 3D space was implemented.

5.4. Lighting & Baking

Users found concern with the visual artifacts created by the baked lighting, as anticipated during the build phase. Users also highlighted that the location of the sun was incorrect in context of the site; calling attention to its incorrect northerly position. Subsequently, further discussion into the sun's position suggested that a dynamic sun path would be beneficial, proposing that the ability to transpose the position of the sun in VR provides a benefit that the original map walk could not. Users addressed that visual elements such as shadows are greatly important in advising where plants and urban agriculture elements should be placed, due to principles such as frost pockets.

5.5. Audio

Feedback and testing revealed that some sounds needed tweaking/improvement/optimization, for example, due to delayed or inconsistent sounds. It was also identified that the spawn object function repeated

5.6. Locomotion and Scene Transitions

Following the first round of feedback, some limitations and difficulties were highlighted in regards to the locomotion system. As discussed, users suggested the following - The locomotion system needed to contain a 'step back' function, to accommodate for ease of use, allowing the user to back out of areas that are challenging to navigate. - "I preferred to walk through the site instead" - Many users found it difficult to learn the controls for moving around in VR, suggesting that some form of tutorial, interactive or otherwise, might assist learning. Users also commented that it would be good to be able to change the elevation (height) of the user to be able to see the site in its entirety from above (bird's eye perspective).

5.7. Modeling and UV Mapping

Due to time constraints, UV mapping was not carried out on objects during the first development build. Consequently, this resulted in a lack of consistency across models in regards to color, lighting, and shadows; a deficiency which was frequently highlighted by feedback from users, with the general consensus being that improvement was needed to create a more realistic and immersive experience. Feedback also commented that environmental details were missing and could be added "There's a lot of iconic street art not captured in the scene". It was also discussed that there was a lack of social spaces, and that social spaces could be integrated into the layout in addition to gardening elements.

5.8. User Interface

Feedback commented that wayfinding needed to be improved to better understand relative position for the setting of the site, in particular in regards to the introductory scene and 3D map…"Where is the station, beach, and where am I now?". This could be addressed via UI text elements placed on the site to provide context to the user.

6. VR Experiment Development (Beta Build)

6.1. Spawn in Place

Due to the timescale of the project, redeveloping the spawn in place system to incorporate the ability to snap to an in game grid was not feasible, thereby in order to address these participant comments, certain refinements were made to the objects and the pre-existing spawn in place system. Additional sizes of planters were introduced to address the varying types of modules, allowing for greater variety while maintaining a limit on options for the sizes available. Subsequently, the fixed 45 degree rotations were reconfigured to be adjustable within the UI menu, down to increments of 11.25 degrees (1/8th of 90 degrees); providing a greater degree of accuracy with their rotational position. Similarly, due to timescales of the project, providing a custom mesh builder and a terrain editing tool was also not possible. In order to address the ability to spawn plants/vegetation and custom objects, a drawing tool was implemented so that the participant could overlay their imaginations in 3D onto the polytunnels/planters/ground. This also helped keep the spawn in place menu short without significantly overwhelming the user with choices. Finally, to aid the conversation regarding objects currently within the scene, an options menu was developed to be able to load pre-configured layouts so that participants could edit/amend as required.

6.2. OSM Modelling

Continuing from the feedback obtained from the alpha build, some alterations were made to the 3D city model. Tags were added onto the model to highlight key landmarks, providing context to the site. The tags utilized the design principles of ‘billboarding’ whereas the text would always face the in-game camera so that the participant could view the model from any angle and be able to understand the context. In addition, blender OSM was revisited to import a texture overlay onto the terrain. The previous model, which used lines to denote roads, gave little context to green areas and bodies of water. By implementing an open street map texture overlay, roads were clearly denoted as well as their corresponding names, and additionally, greenscape and bluescape were presented clearly which aided in the conversation surrounding urban agriculture.

6.3. Drawing Tool

The drawing tool utilized the tracking of the VR controllers to allow users to draw in the 3D environment. Much of this tracking data has been processed and made easily accessible using Unity’s XR Toolkit. Using this data, two additional events were created; “Started()” and “Canceled()”. Simply, these events are invoked when the trigger is pressed and the trigger is released respectively. When “Started”, the following methods are executed. Firstly, the user interface menu is hidden so that the user can see what they are drawing. Secondly, a new ‘line renderer’ object is instantiated at the current position of the controller, this line renderer object is spawned with a numerical suffix to allow differentiation between the line objects. Beyond this, a loop is triggered so that a new point of the line renderer is added each frame, meaning that as the controller moves, the new position of the controller is added to the points list of the line renderer. When “Canceled”, the loop is set to false so that the drawing mechanics do not continue to run. In addition, the UI menu reappears to allow the selection of other menus. Lastly, a box collider is formed around the extends of the newly created line so that the delete cool can register the collisions to allow the user to remove any drawing they have done. When tested, it was found that the original method of raycasting to delete objects meant that hitting the line object was very challenging, especially at a distance. To aid in the deletion of these drawings, the delete tool utilized ‘spherecasting’, utilizing similar principles to raycasting with the added benefit of capturing a larger scope of objects; returning the closest object to the user as the collision.

6.4. Lighting & Baking

In order to correct the visual artifacts created by the poor UV map exports, the models were re-mapped using Blender. Once remapped, these were reimported into Unity and re-baked. The lighting settings were altered to account for the implementation of dynamic lighting; ‘Baked Indirect’ lighting was utilized so that building depth was captured while allowing the direct lighting to move within the scene. In order to implement the sun path, data was taken from open source online tools to obtain the azimuth and altitude at certain points of the day during a specific time of the year. For this application, the position of the sun was captured every two hours from 6am to 6pm. This data was implemented onto the scene direct lighting object and made adjustable using a slider within the UI menu.

6.5. Audio

During the 2nd stage of development, sound performance was improved, including trigger-enabled sounds, such as the spawn object functionality. To reduce audio overlap caused by the spawn in place function, the frequency of the ‘on-trigger' variable activation was reduced.

6.6. MiniMap

In feedback stage one, the need for a real-time bird's-eye perspective was highlighted. This led to the development of a Minimap system. This was created through implementing another scene camera and displaying it as a UI element that the user could enable on demand. Another camera was set up and applied to the XR Origin so that it would follow the position of the user. The view aspect was set directly above the player and angled down in bird’s eye perspective, with the projection set to ‘orthographic’ to create a 2D view with no perspective. A new UI element, a ‘Raw Image’ was created which serves as a host that the camera image can be rendered onto as a texture rather than a sprite - as is typical with UI elements - and was applied under the UI controls of the left hand controller, to show up on activation. A Render Texture was created for this purpose to serve as the texture input on the Raw Image, the Render Texture is then applied as the output texture of the camera. The player’s position relative to the surroundings would be difficult to see on the map, as only two controllers make up the 3D physical representation of the player, as such a large red sphere object was used and bound to the player’s origin to better indicate this. The sphere was set to only be visible on the 2D Minimap display so as not to interfere with the main user viewport.

6.7. 360 Photograph Walkthrough

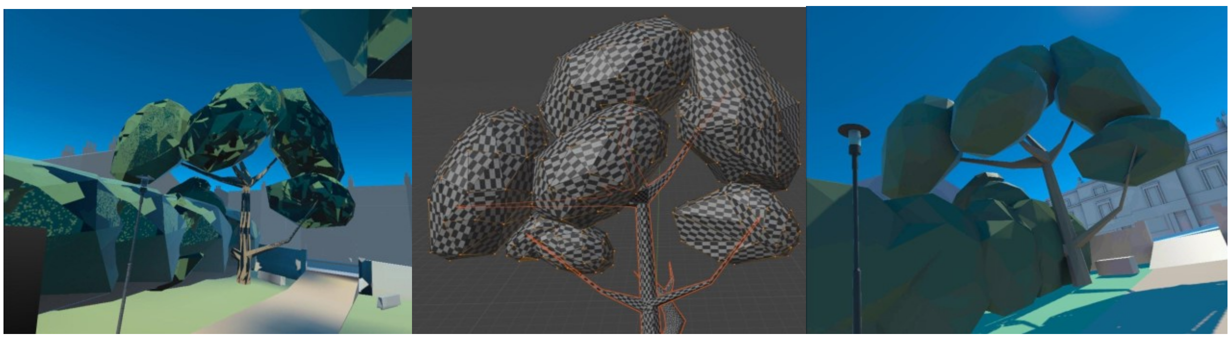
In response to feedback from participants after development stage 1, it was suggested that it would be beneficial to be able to conduct a map walk virtually, for those who cannot attend physically or as a reminder for participants. As such, a walkthrough tour was created using 360-degree photos. The process was carried out within Unity, whereby captured 360 photos were imported as textures and ‘Cube’ shape applied, turning the image into a cubemap, which is necessary to create a skybox later on. A new material is then created utilizing the texture and ‘Cubemap’ type shader applied which can be allocated as a 'Skybox' overlay to the VR camera. Several scenes were set up, each with their own skybox (360 image) and navigation between which was handled using the aforementioned scene loading, here applied to user interface elements on an information stand (3d model).

6.8. Locomotion and Scene Transitions

It was decided that a 'step back' function not be added to the controller functions as it would have made the controls too complicated for the users with an already extensive list of controls and functionality. Instead a UI-based explanatory tutorial was added to explain controls. Due to limitations with time, the interactive tutorial aspect was not investigated. Following testing of the elevation change functionality, it was decided that this be handled differently due to the potential exposure of the model boundary, as well as the potential loss of scale/proportions at ground level. Instead the Minimap approach was implemented to resolve this concern.

6.9. Modeling and UV Mapping

To address stage 1 feedback. all items were UV mapped in Blender before being exported to Unity. The surface faces of the 3D object are "unwrapped" and aligned with an assigned texture along defined edges to create a "seamless" look across separate surfaces. In turn, this allowed the baked lightmap textures to render correctly on the 3D objects within the scene.



Figures 1: a) Tree model with texture & lighting issues; b)UV map scaling check; c) Post mapping & re-lighting

6.10. User Interface

In addressing lack of wayfinding, 'Billboard' UI text was attached to key locations on the 3D map. The billboard effect is applied to text within Unity by rotating the text object so that its forward direction always points towards the camera, this is achieved through scripting or built-in components such as the Billboard Renderer. This made it useful for indicating or labeling items, creating head-up displays (HUDs), speech bubbles, and other types of on-screen text that should always be visible to the player.

7. Experiment Feedback (Beta Build)

7.1. Spawn in Place

Following the presentation of the beta build, the feedback reflected similar themes to the previously obtained feedback from the alpha build. Participants suggested that having a grid/snap system was very desirable and perhaps should have taken a greater priority in the development. Furthermore, the participants went on to discuss expanding this grid to vertical planes, introducing the principles of vertical urban agriculture. Additionally, by having pre-existing objects within the scene, participants provided comments on developing an 'edit' tool, albeit neither a spawn or delete tool, but the ability to manipulate existing objects in place, be that position or rotation. Lastly, some users felt that icons were not representative of what was being spawned and would have preferred 3D representations of these spawnable objects rather than a 2D icon.

7.2. OSM Modelling

The participant comments on the beta build came across as promising, with many suggesting that the billboarding text applied to the 3D city model helped provide a lot of context to what they were visualizing and they could easily navigate to the site in question. In light of this, little feedback was suggested for the city model, suggesting that this was developed to a suitable level of detail. Despite this, when in the 1:1 model, some participants alluded to providing context for the site utilities, whereby water and other underground assets could be used for the purposes of urban agriculture. Previous research has suggested that despite local authorities making their utility data more accessible, there is still a lack of digital formats (Piroozfar et al., 2019) thereby making this difficult to implement into such a model.

7.3. Drawing Tool

The feedback obtained from the drawing tool was generally positive and users found that they were able to communicate their intentions better with a drawing tool implemented. Some responses suggested that the indication that the drawing would originate from the controller was unclear, and that this should be made more obvious, perhaps by means of a visual tutorial or larger more prominent indicator. Some participants also suggested having the tool project onto 2D horizontal and vertical surfaces, similar to how a spray can would work. This would allow users to highlight boundaries and compartmentalize the site to aid in the discussion into urban agriculture. Following this suggestion, it was also highlighted that with different zones, different colors would be required to help differentiate the drawings created.

7.4. Lighting & Baking

Following the updates to the Alpha build, users resonated with the newly implemented sun path, suggesting that further times/positions of the sun could be added to hone in on shadow positions. Users also suggested that pre-defining frost pockets with zones/areas may be easier to interpret than adjusting the position of the sun. Users also suggested that the baking had been improved since the last build, making it feel less ‘glitchy’.

7.5. Audio

The final feedback stage suggested that adaptive audio could improve realism and immersion whereby audio responds intelligently to user action. A single beehive, for instance, would sound different from a group of six beehives and not necessarily six times the volume of a single beehive. This approach might also avoid audible feedback loops that result in intense, confusing and unrealistic sounds

7.6. MiniMap

Following feedback and in addition to the added sun positioning feature, users suggested that having a compass would have been essential for understanding and orienting oneself in relation to the north. Furthermore, to be sure that they were planting and orienting their plants in the correct direction to ensure optimal growth, a feature that would be valuable to gardening.

7.7. 360 Photograph Walkthrough

Feedback discussed that the photos gave a sense of scale, particularly due to having people in the photos. Suggesting that human scale should be implemented within the digitally created VR scene also.

Figures 2 a): Sun positioning; b) Minimap & upper perspective; c) OSM model & billboard text; d) Drawing tool

7.8. Locomotion and Scene Transitions

After a second round of feedback, the 360 walkthrough scene was added which also comprised use of the scene loader to enable transition between each of the various 360 degree photos as part of the walkthrough scene.

7.9. Modeling and UV Mapping

The final round of feedback discussed the idea of including 360 photos with people, for scale reference, inside the 3D constructed scenes as well. The gardening site scene was noted as somewhat repetitive, further development might seek to add variation. Additionally, for the spawn feature, a method of vertical spawning could be provided - not only on the ground plane - so that elements such as climbing walls and green walls can be included.

8. Concluding Comments and Future Research

This research focused on the development process of a Virtual Reality (VR) experiment, which was driven largely by feedback from community stakeholder groups. This paper outlines the Alpha and Beta development phases, as well as the 1st and 2nd rounds of participant feedback. It details the process and improvements made to the VR application.

While developing, emphasis was placed on using predominantly free or open source tools, rather than "off-the-shelf" solutions and software. A cost-effective alternative to proprietary software, this strategy also encouraged customization and collaboration - Github enabled developers to collaborate. Unity game engine enabled a high degree of customization and, while more challenging than some off-the-shelf VR solutions, proved advantageous due to the greater level of flexibility that met the requirements of this research design. Similarly, the utilization of OpenXR standard significantly reduced development time, eliminated compatibility issues, improved user experience and performance reliability.

Through investigation of the areas discussed by participants in different stages of this study, and in particular that of the beta phase of development, the research can be further developed with continued development of the application. Feedback suggested that various modalities and optimizations could be implemented to improve the spawn in place system, particularly with regards to the 'snapping' functionality. Additionally, it was suggested that a 'world' grid system be developed to aid with space planning, allowing the placement function to be guided for ease-of-use.

Participants also advocated for more customizability regarding the spawnable 3D objects, expressing that the ability to manipulate and transform the pre-defined metrics of the objects would be constructive. This was partly resolved through inclusion of the drawing tool which provided a 'sandbox'-type, or open-ended, creativity tool.

Several potential routes for development became apparent through the development stage were not highlighted by user participants, which was due in some part to being concerned more with back-end than front-end software (i.e. the functionality or data management of the application as opposed to that of user-facing). More advanced methods for data collection could be utilized, such as logging and storing user inputs digitally (hard drive or cloud-based) to be analyzed at a later point, and for example, facilitated through inclusion of metadata to enable description, assessment and management of the data to take place.

Another consideration not discussed by participants but considered important by the developers is the development of an augmented reality (AR) application alongside a VR counterpart. This could enable the user to interact with their environment more effectively, as well as providing an additional layer of immersion. A test run and pilot study could be run in the same regards as has been carried out with this research for VR.

On the way towards an extended study and further research there is scope for extension towards other urban spaces each perhaps presenting their own obstacles and possibilities. Although many of the above-mentioned areas were concentrated and improved during the several rounds of iteration for application development in this study, there is still more work to be done in those areas, which will set the target for future research in many of those areas.

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BIM-LCA Integration for Carbon Emission Assessment in Construction Industry: Systematic Review and Research Opportunities

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Abstract
A systematic literature review explored the integration between Building Information Modeling (BIM) and Life Cycle Assessment (LCA) for carbon emissions assessment in the construction industry to identify primary research studies published in English between 2017 and 2022 that focused on this integration. Data were extracted from the included studies and analyzed using qualitative synthesis approaches, including content and thematic analysis. The study found that integrating BIM and LCA provides numerous benefits for enhancing sustainability and reducing environmental impact in the construction industry, including improved building design and construction, optimization of building materials, and the ability to make informed decisions regarding carbon reduction. The review identified several commonly used BIM and LCA tools, explored a wide range of applications of BIM-LCA integration, and presented various case studies that demonstrated its benefits. However, the study also identified several limitations of BIM-LCA integration, including technical challenges and the need for more real-world projects, best practices for integration, and analysis of the barriers to adoption in Thailand's construction industry.

Keywords
Building Information Modeling (BIM), Life Cycle Assessment (LCA), BIM-LCA Integration, Carbon emission assessment, Carbon Reduction

1. Introduction

One of the major producers of CO_2 emissions worldwide is the building and construction sector (Bueno & Fabricio, 2018; Onat & Kucukvar, 2020). The World Green Building Council estimates that this industry is responsible for around 39% of the world's energy-related carbon emissions, substantially contributing to climate change. The building and construction sector must embrace sustainable building techniques and cutting-edge technology as the globe places a greater emphasis on lowering greenhouse gas emissions (Doan et al., 2017; Marrero et al., 2020). The manufacturing of building materials, the use of energy during the construction and operation of structures, and the transportation of workers and materials are all factors that contribute to the overall carbon emissions produced by the sector. There is potential for the construction sector to cut its carbon footprint via the adoption of innovative technology and environmentally responsible building practices. Carbon emissions have been the primary concern for the building and construction sector, particularly concerning the production of materials, energy consumption, transportation, waste management, and construction activities. (Mao et al., 2013). The rise in CO_2 is considered a factor in which climate change will severely affect humanity, including weather unpredictability, agricultural instability, and public health issues (Nema et al., 2012).

When it comes to addressing the challenges of cutting down on CO_2 emissions, innovations in building and construction technology may be crucial. Various tools and methods have been developed, including BIM and LCA (Teng et al., 2022). Building Information Modeling, often known as BIM, is a digital representation of a structure's structural and functional aspects used in building planning, construction, and operation. BIM allows for improved collaboration and communication between project stakeholders and provides valuable insights into the performance of buildings (Cerovsek, 2011; Ghaffarianhoseini et al., 2017). On the other hand, Life Cycle Assessment, often known as LCA, is a tool used to examine a product or service's effect on the environment during its entire life cycle, which includes the extraction of raw materials, manufacture, usage, and disposal. (Rebitzer et al., 2004). Integrating BIM and LCA can potentially revolutionize the way the construction industry assesses and reduces its carbon footprint. By modeling and simulating the performance of buildings with BIM and assessing the environmental impact of building materials and systems with LCA, the construction industry can make more informed decisions, which in turn leads to a reduction in carbon emissions (Tam et al., 2023).

The literature on BIM-LCA integration for carbon emissions assessment in the construction industry is expanding. Multiple studies have determined that BIM and LCA can be combined to provide a more comprehensive and accurate picture of carbon emissions in the building and construction industry. BIM is a technology that transfers information and allows interoperability between various design software tools. Moreover, it can be used to optimize material choices and reduce waste during construction, which can help reduce carbon emissions (Kamel & Memari, 2019). LCA has helped construction companies assess carbon emissions. ISO established LCA methodology standards in the second half of the 1990s. LCA quantifies a product's environmental impact using ISO 14040 framework. It considers the whole product life cycle, from procuring raw materials to recycling or disposal. Since 1990, the LCA technique has been extensively utilized in the construction industry to evaluate the effect that various building materials have on the environment throughout the life cycles of individual projects (Fava, 2006). Several studies have found that LCA can comprehensively understand the environmental impact (Tam et al., 2022).

Construction activities and environmental impacts are analyzed throughout a project's lifespan. The LCA-based method can identify and assess carbon emissions in various stages, from construction materials, transportation, equipment, and fuel and disposal impacts (Safari & AzariJafari, 2021; Yang et al., 2018). This information can be used to optimize building design and construction practices and reduce buildings' environmental impact. In addition, Life Cycle Assessments (LCAs) in the form of Environmental Product Declarations (EPDs) for building materials give information on the effect that building goods have on the environment. (Bovea et al., 2014). For instance, the EPDs available for insulation materials can provide architects and engineers with helpful information that can assist them in making educated choices regarding the types of materials that should be utilized to lessen the negative impact a building has on the surrounding environment (Soust-Verdaguer et al., 2022).

Overall, BIM-LCA integration has the potential to considerably enhance carbon emissions assessment in the building and construction industry. It was mentioned that a multidisciplinary approach is necessary to minimize the environmental impacts of buildings, and the use of BIM can reduce the efforts of LCAs (Kamari et al., 2022; Xue et al., 2021). The integration process must address organizational and technical issues. The information necessary for the LCA analysis must comply with the study's objectives and scope, as well as the information structure established during the design stage (Rosen & Kishawy, 2012). The challenges and potential advancements of BIM and LCA integration include the data transformation between BIM and LCA platforms (Seyis, 2020). For example, there needs to be more standardization in the use of BIM for LCA, which can lead to inconsistent results.

Furthermore, the accuracy of the LCA findings is contingent upon the quality and completeness of the BIM model, which may be a difficulty for both the designers and the practitioners (Bueno & Fabricio, 2018). There is still a need for more research on the effectiveness of BIM-LCA integration in real-world projects, as well as more research on best practices for integrating BIM and LCA and barriers to adopting BIM-LCA integration in the construction industry, such as technical challenges and cultural resistance. There is still much work to be done to fully grasp the possibilities of this approach and create the best methods for putting it into action. Therefore, this paper aims to conduct a literature review to summarize and evaluate the current state of BIM-LCA integration in the building and construction industry, providing an overview of the existing literature, highlighting the main findings and conclusions from previous research studies, and identifying gaps or areas where further research is required to support the application of BIM-LCA integration in Thailand's construction industry. This study synthesizes multiple studies, combining the results of various research studies to provide a comprehensive picture of BIM-LCA integration. It also provides a complete, up-to-date summary of the current state and identifies future research directions; it also includes a barrier, limitations, and areas for improvement.

2. Methodology

This literature analysis was done to provide an all-encompassing overview of the BIM-LCA integration for carbon emissions assessment in the building sector. This study applied a systematic review to investigate the current state of research on the integration of BIM and LCA in the construction industry. A comprehensive search of academic databases and reviewed reference lists of relevant articles were conducted to identify primary research studies published in English between 2017 and 2022 that concentrated on using BIM and LCA in the building and construction industry. The search results were screened by title and abstract and included studies that met our inclusion criteria: primary research studies published in peer-reviewed journals or conference proceedings. Data were extracted from the included studies on study design, research objectives, BIM and LCA tools and methods, applications and case studies, and limitations and future research directions. In the process of analyzing the data, a qualitative synthesis approach was utilized, which included both content analysis and thematic analysis. Our findings are reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA guidelines) for systematic reviews. A narrative synthesis of the data, including a summary of the main themes and patterns that emerge from the analysis, was also provided in this paper.

This review conducted a comprehensive search of several databases, including Scopus, Web of Science, and Google Scholar, to identify relevant articles, reports, and studies by providing specific search terms to ensure their search was focused and relevant. The bibliometric analysis involves using quantitative methods to analyze scientific literature to understand knowledge production and dissemination patterns.

The title, keywords, and abstract criteria of topic areas about building information modeling, life cycle assessment, project life cycle assessment, CO_2 emission assessment, and construction project were used as a reference for collecting search results. The keywords were searched by using the terms which include TITLE-ABS-KEY: [“BIM-LCA integration” OR “carbon emissions assessment” OR “construction industry” OR “project life cycle”] and TITLE-ABS-KEY: [“building information modeling” AND “BIM” AND “life cycle assessment” AND “LCA”]. The inclusion criteria were used to select articles, reports, and studies for their review. The articles, reports, and studies were carefully reviewed and analyzed to identify the key findings, trends, and gaps in the literature. There were numerous publications on BIM-LCA integration from 2017 to 2022, with 1,764 articles found in the Scopus database on November 25, 2022. The results of 1,764 findings from the databases were exported to excel files. Following the review of the titles and abstracts, 620 articles were deemed ineligible for inclusion because they did not satisfy the inclusion criteria. Following an evaluation of the complete versions of the remaining 1,144 articles, a selection of 50 articles was made for the purpose of this review.

3. Results and Discussion

The integration of BIM and LCA has become increasingly popular in the construction industry, as it offers numerous benefits for improving sustainability and reducing environmental impact. The findings of bibliometric mapping were evaluated by country and keywords. The 32 included studies were published between 2017 and 2022 and were conducted in various countries, including China, the United States, the United Kingdom, Canada, Australia, etc. The studies used a range of research designs, including case studies, experiments, and surveys. The sample sizes of the studies ranged from single-building projects to large-scale industry surveys.

The literature review on the BIM-LCA integration for carbon emissions assessment in the construction industry revealed several key findings. BIM and LCA were found to have significant potential to be applied for reducing carbon emissions in the construction industry, and their integration was found to provide a more comprehensive picture of the carbon footprint of a building (Li, 2021). The research used a variety of BIM and LCA technologies and approaches to integrate BIM and LCA in the construction sector. Autodesk Revit, ArchiCAD, and Tekla Structures were among the most popular BIM software solutions. SimaPro, EcoInvent, Gabi, and One Click LCA were some of the most popular LCA applications. BIM and LCA were integrated into these studies using a variety of approaches, such as parametric modeling, simulation, and optimization, among others.

The studies explored various possible uses and applications of BIM-LCA integration in the construction industry, encompassing architectural design, construction planning, and existing facility administration. The studies also presented various case studies that demonstrated the benefits of BIM-LCA integration, such as decreased influence on the environment, increased quality of air within buildings, and lower energy usage (Dalla Mora et al., 2020). This means BIM and LCA have a significant relationship together. Improving stakeholder cooperation is one of the primary advantages that may be gained by merging BIM with LCA. Using a single, integrated platform to model the building or infrastructure project, all stakeholders can access and share data in real time, reducing the possibility of misunderstandings, errors, and delays. This can result in more efficient and cost-effective project management and improved sustainability outcomes (Huang et al., 2020).

Another benefit of BIM-LCA integration is an improved decision-making (Chan et al., 2022). Stakeholders may find ways to lessen the negative effects on the environment and boost the project's sustainability by conducting an environmental impact analysis. This can include optimizing the building design, selecting materials with lower environmental impact, and reducing energy consumption. Using objective data to inform decision-making, stakeholders can make more informed choices about resource use and environmental impact reduction (Motalebi et al., 2022; Sharif & Hammad, 2019).

The studies identified several limitations of BIM-LCA integration. Technical challenges, such as compatibility between BIM and LCA software and standardization in data formats, can make it challenging to implement BIM-LCA integration in the practice (Safari & AzariJafari, 2021). Table 1 summarizes previous research integrating various BIM-LCA integration techniques into construction projects. However, there is a need for more studies on the effectiveness of BIM-LCA integration in real-world projects and more research on the best practices for integrating BIM and LCA. Cultural resistance, including a lack of understanding of the benefits of BIM-LCA integration and a lack of incentives for adoption, can also be a barrier to implementation (Olanrewaju et al., 2022).

Moreover, there is a need for more research on the barriers to adopting BIM-LCA integration in the construction industry, including technical challenges and cultural resistance, and to develop best practices for BIM-LCA integration in the construction industry (Zimmermann et al., 2021). In the future, more studies should be conducted on the information sharing between BIM and LCA throughout various project lifecycle phases. This would help expand the BIM-enabled LCA to an enormous scope of sustainable construction by including other sustainability metrics or scenarios, such as renewable energy sources, interior comfort, resource consumption, etc. (Llatas et al., 2020).

Table 1. BIM-LCA integration into construction project: Summary from previous research

Type of building/ References	BIM authoring tool	LCA Tool	Method of data exchange and format	Information shared from BIM to LCA platform	Contribution	Challenges and limitations
Multi-story office building in Brazil (Najjar et al., 2017)	Autodesk Revit	Green Building Studio/ Tally/ GaBi	Direct link/ Revit plug-in/ Parametric modeling/ Simulation	Geometry/ Material data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Incorporation of BIM and LCA methodologies in the early stages of construction project design	Insufficient BIM database
Residential building in China (Yang et al., 2018)	Autodesk Revit 2015 (LOD300) MagiCAD	eBalance software/ Chinese Life Cycle Database/ Designbuilder (Version 4.5.0.148)	Exporting data/ gbXML file/ Parametric modeling/ Simulation	Geometry/ Material data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Improved environmental performance/ Building energy simulation/ Optimized building performance	Limited interoperability between BIM and LCA tools/ Need for specialized expertise
Single-family house in Belgium (Santos et al., 2019)	Information Delivery Manual (IDM)/ Model View Definition (MVD)	IFC4 schema/ EPDs/ Ecoinvent database	Exporting data/ IFC file/ gbXML file/ Direct link/ Parametric modeling	Geometry/ Material data/ Equipment and systems data/ Maintenance/ Replacement schedules	Improved environmental performance/ Cost savings	Limited availability of LCA data/ Limited interoperability between BIM and LCA tools
Hospital Building in China (Lu & Wang, 2019)	Autodesk Revit 2017 (LOD 300)/ Glondon GTJ2018	Green Building Studio	Direct link/ Simulation	Geometry/ Material data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Improved environmental performance/ Optimized building performance	Limited interoperability between BIM and LCA tools

Type of building/ References	BIM authoring tool	LCA Tool	Method of data exchange and format	Information shared from BIM to LCA platform	Contribution	Challenges and limitations
Multi-apartment building in Germany (Yayla et al., 2021)	Simplified BIM models belonging to SBS database	GaBi	Direct link/ Simulation	Geometry/ Material data/ Energy performance/ MEP system	Improved collaboration and communication/ Enhanced stakeholder engagement	Limited availability of LCA data and specific energy consumption/ Time and resource constraints
Guangdong Inkstone Culture Museum in China (Cheng et al., 2020)	Autodesk Revit/	Design-builder software	Exporting data/ gbXML file/ Direct link/ Simulation	Geometry/ Material data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Improved environmental performance/ Optimized building performance	Need for future enhancement of the compatibility of multiple BIM systems
The historical heritage of the city of Matera, Italy: Palazzo del Sedile (Selicati et al., 2020)	Design-builder Model	SimaPro v.8.5.2.0/ EPDs/ EnergyPlus™/ Ecoinvent3, ELCD and Industry data 2.0	Data exchange platforms/ Simulation	Geometry/ Materials data/ Energy performance/ Equipment and systems data/ Maintenance/ Replacement schedules	Improved environmental performance/ Optimized building performance/ Enhanced stakeholder engagement	Limited availability of LCA data/Integration of social and economic factors
Residential apartment complex in the territory in India. (Kurian et al., 2021)	Autodesk Revit Architecture 2018	GaBi database/ EPDs/ Ecoinvent databases through One Click LCA software/ ICE database	Parametric modeling/ Direct link	Geometry/ Materials data/ Energy performance/ Equipment and systems data/ Maintenance/ Replacement schedules	Improved environmental performance	Limited availability of LCA data
Educational institutions in Peru (Vázquez-Rowe et al., 2021)	BIM3D model/ Comparative Monte Carlo (MC) simulation	Peru LCA, the Peruvian LCA database	Manual Export/ Direct link/ Simulation	Geometry/ Materials data/ Equipment/ Fuel/Energy/ Maintenance/ Replacement schedules	Improved environmental performance/ Optimized building performance/ Enhanced stakeholder engagement	Lack of standardized methods and tools/ Limited interoperability between BIM and LCA tools/ Integration of economic factors
Urban Transformation in Istanbul, Turkey (Yayla et al., 2021)	Autodesk Revit	Green Building Studio	Manual Export/ Direct link/ Simulation	Visualization/ Spatial data/ Building geometry data/ Building envelope characteristics	Improved environmental performance/ Cost savings/ Optimized building performance/ Enhanced stakeholder engagement	Lack of standardized methods and tools/ Time and resource constraints
Real-life prefabricated building in Hong Kong (Xu et al., 2022)	Autodesk Revit	SimaPro	BIMToSimaPro/ The Industry Foundation Class (IFC) data format	Geometry/ Materials data/ Energy performance/ MEP system/ Maintenance/ Replacement schedules	Improved environmental performance	Limited interoperability between BIM and LCA tools

In addition, content analysis of BIM-LCA integration involves examining the specific data and information used in integrating BIM and LCA and analyzing how this data is organized, evaluated, and communicated. A thorough content analysis can gain insights into the strengths and limitations of the approach and opportunities for further improvement. This section will explore the critical components of BIM-LCA integration, including BIM content, LCA methodology, environmental impact categories, data sources, and limitations, and provide a detailed analysis below.

3.1 The overview of BIM-LCA integration

Several building and construction case studies have successfully integrated BIM and LCA (Asare et al., 2020; Najjar et al., 2017; Obrecht et al., 2020a). The literature demonstrates the potential of BIM-LCA integration for reducing carbon emissions and provides valuable insights into the implementation's key benefits and challenges (Potrč Obrecht et al., 2020). The authors propose a BIM-based LCA approach to enhance the sustainability of the buildings (Hollberg et al., 2020; Obrecht et al., 2020b; Soust-Verdaguer et al., 2017; Xue et al., 2021), as well as three methods for linking BIM and LCA, which include the quantification of materials, the incorporation of environmental information into BIM software, and the creation of an automated process that combines various data and software. However, the case studies also highlight some challenges of implementing BIM-LCA integration in the construction industry (Safari & AzariJafari, 2021). The need for compatibility between BIM and LCA software and standardization in data formats can make it challenging to integrate the two technologies in practice. BIM offers information for storing multi-disciplinary data and automating and connecting the many phases of the design process. Nevertheless, it has a few drawbacks, such as the fact that the entire life cycle effects of the construction materials must be entered manually, interoperability problems, and the possibility of human mistakes (David Mineer, 2016).

3.2 Benefits of integrating BIM and LCA

BIM and LCA are two significant techniques increasingly utilized in designing, constructing, and managing buildings and construction. Integrating these two approaches can bring many benefits to building projects, such as better decision-making, improved sustainability, increased efficiency, improved communication, and better documentation. Because of the BIM-LCA integration, architects, engineers, and contractors are now able to evaluate a variety of design alternatives, consider the ramifications of those alternatives with regard to the environmental impacts and cost implications, and then arrive at well-informed judgments. Integrating LCA with BIM makes it possible to identify opportunities for reducing the environmental impact of a building and to make design changes to improve sustainability. BIM provides a centralized and collaborative platform for managing building design data, making it easier for all project team members to access and share information. Then LCA offers a comprehensive evaluation of the environmental impact that a building has throughout its entire life cycle. Integrating LCA into the BIM process streamlines the LCA analysis process, reducing the time and cost associated with producing separate LCA reports. Finally, integrating BIM and LCA provides a more holistic and comprehensive approach to building design, construction, and operation, resulting in more sustainable, efficient, and cost-effective buildings (Asare et al., 2020; Azizoglu & Seyis, 2020; Potrč Obrecht et al., 2020)

3.3 Challenges and limitations of BIM-LCA integration

While BIM-LCA integration can bring many benefits to building projects, several challenges and limitations must be overcome to realize the full potential of this approach. Some key challenges and limitations include the following: First, data quality and accuracy are crucial for both processes; inaccurate data can lead to incorrect LCA results and limit the usefulness of the integration. Second, integrating data between BIM and LCA tools requires a seamless exchange of data, which can only be challenging with proper tool design. Third, a lack of standardization in data and methods can make it difficult to compare results and limit the consistency of the environmental impact assessment. Fourth, integrating BIM and LCA requires high technical expertise, which can hinder adoption for some organizations. Fifth, integrating BIM and LCA can be time-consuming and costly, making it difficult for some organizations to justify the investment. Finally, data security and privacy concerns may limit the willingness of some organizations to participate in the integration process. Despite these challenges, integrating BIM and LCA is critical for creating more sustainable, efficient, and cost-effective buildings. Overcoming these challenges and limitations can lead to a more holistic and comprehensive approach to building design, construction, and operation (Genova, 2018; Obrecht et al., 2020a).

3.4 The research gap in BIM-LCA integration

Despite the rapid growth and increasing importance of BIM-LCA integration, there are still significant research gaps in this field. Some of the key research gaps include (Obrecht et al., 2020b; Theißen et al., 2020; Xue et al., 2021):

1. Integration of multiple LCA methods: While BIM-LCA integration has made significant progress in recent years, there is still a need for better ways to integrate different LCA methods and tools and to standardize the data and results generated by these tools.

2. Improved data quality and accuracy: The quality and accuracy of the data generated by BIM-LCA integration are critical to the correctness and dependability of the findings. However, there is still a need for better methods to ensure this data's quality and accuracy and mitigate the impact of data gaps and uncertainties on the results.
3. Integration with other sustainability assessment tools: BIM-LCA integration is just one of many tools used to assess the sustainability of buildings. There is a need for greater integration of BIM, LCA, and other sustainability assessment tools, such as Energy Performance Assessment (EPA) and Building Performance Simulation (BPS), to provide a more thorough perspective of the environmental impact of buildings.
4. Standardization and interoperability: To ensure that the results of BIM-LCA integration are consistent, reliable, and meaningful, there is a need for greater standardization and interoperability in the methods and tools used for data analysis and reporting.
5. Improved user-friendliness: While BIM-LCA integration has become more accessible in recent years, there is still a need for better methods for making the integration process more user-friendly, especially for non-expert users.

The research gaps in the field of BIM-LCA integration highlight the need for continued research and development in this area. By addressing these gaps, organizations can continue to make the integration process more effective, efficient, and reliable and make better-informed decisions about the environmental impact of their buildings.

3.5 The future of BIM-LCA integration and opportunities for further research and development.

BIM and LCA are evolving fields with many opportunities for further research and development. Integration of BIM and LCA has excellent potential, and there are numerous opportunities for further research and development in this area. By utilizing the most recent technologies and methodologies, organizations can continue to make the integration process more effective, efficient, and reliable and make more informed decisions regarding the environmental impact of buildings.

Based on the results of the literature review and case studies presented in this paper, the following recommendations for future research on the topic of BIM-LCA integration for carbon emissions assessment in the construction industry are made:

1. Further development of BIM-LCA integration software: To fully realize the potential of BIM-LCA integration, it is important to continue to develop compatible software that can communicate between BIM and LCA platforms. This will enable more accurate and efficient analysis of building design and construction decisions in terms of their impact on the environment.
2. Standardization of data formats: The need for more standardization in data formats presents a challenge for BIM-LCA integration. Industry organizations and standards bodies are recommended to collaborate to develop and implement standard data formats for BIM-LCA integration.
3. Increased use of BIM-LCA integration in practice: Despite the potential benefits of BIM-LCA integration, there is limited evidence of its use in practice. It is recommended that industry stakeholders encourage and support the adoption of BIM-LCA integration in the construction industry by providing education and training and developing best practice guidance.
4. Further case studies and comparative analysis: The case studies presented in this manuscript provide valuable insights into the potential of BIM-LCA integration for reducing carbon emissions in the construction industry. However, more case studies are needed to better understand the benefits and challenges of BIM-LCA integration in different contexts and to provide a more comprehensive understanding of the potential of BIM-LCA integration for reducing carbon emissions.
5. Investigation of the impact of BIM-LCA integration on other sustainability indicators: This review has focused on the potential of BIM-LCA integration for reducing carbon emissions. Nevertheless, it is also vital to explore the influence of BIM-LCA integration on other sustainability metrics, including resource usage, water consumption, and waste production, to give a complete knowledge of the environmental impact of building design and construction choices.

These recommendations provide a framework for future research on the issue of BIM-LCA integration for carbon emissions assessment in Thailand's construction industry. Hopefully, this review will contribute to the ongoing development of strategies and methods to lower the number of carbon emissions produced by the building and construction sectors.

4. Conclusion

Integrating BIM and LCA can play a significant role in reducing carbon emissions in the construction industry. The results of the literature review suggest that BIM-LCA integration can provide valuable insights into the environmental impact of building design and construction and help to reduce the carbon emission of the building and construction industry.

The benefits of BIM-LCA integration include optimizing building design to reduce energy use and the carbon footprint of building materials and to evaluate the environmental impact of a building over its entire life cycle, from material extraction to demolition. This can help identify opportunities to reduce a building's carbon footprint, optimize material choices, and inform design, construction, and operation decisions. Moreover, BIM-LCA integration can help promote sustainable building practices and reduce the environmental impact of the construction industry.

However, there are still significant research gaps in this field, but progress has yet to be made in recent years. Several challenges and limitations need to be overcome to realize the full potential of this approach, including the need for compatibility between BIM and LCA software and the need for standardization in data exchange and formats. BIM-LCA integration is a cross-disciplinary field that requires collaboration between architects, engineers, sustainability professionals, and others. There is a need for more advanced methods for analyzing and interpreting the data generated by the integration, including the development of more sophisticated LCA algorithms and models. By utilizing the most recent technologies and methodologies, organizations can continue to make the integration process more effective, efficient, and reliable, as well as make more informed decisions regarding the environmental impact of buildings, and professionals can analyze the environmental impact of different design and material choices.

The key findings and insights from this research provide valuable guidance for those considering the implementation of BIM-LCA integration in Thailand's construction industry and highlight the need for further research to get ready for this technology. Adopting and implementing BIM-LCA integration in Thailand may need help, such as a need for more awareness and knowledge among stakeholders, limited availability of local data and tools, and the need for collaboration and coordination among different parties involved in the building design and construction process. There are also possibilities for BIM-LCA integration to contribute to Thailand's sustainable construction development.

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Author(s): Wilasinee Samniang, Kriengsak Panuwatwanich, Somnuk Tangtermsirikul and Seksan Papong

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Post-Pandemic Factors Improving Performance in Building Projects of Sindh. A Contractor Perspective

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Abstract

Coronavirus highly damaged the construction industry globally including the construction industry of Pakistan. The coronavirus impacted the world economy as well as health sectors. The government decreased the construction budget for ongoing projects which affected the performance of projects and has a negative outcome for stakeholders, resulting face financial crises in the completion of projects. This research examines factors that could improve the performance of building projects in Sindh after the post-pandemic. This research used quantitative analysis through a questionnaire survey form, distributed to employees working with contractors and involved in building projects in Sindh Pakistan. Received data analyzed through the Average index method to identify factors were (1) Revising the project budget, (2) a safe working environment, (3) improving the e-communication system, (4) centralizing project data, (5) Timely payment, (6) Extension of time, and (7) Timely decision making. This finding helps construction stakeholders manage and improve building projects' performance after the post-pandemic situation.

Keywords

COVID-19, Building Projects, Project Performance, Project Challenges

1. Introduction

COVID-19 has the biggest challenge worldwide. Kalumbu Nsefu & Mishengu Mwanaumo, (2021) mentioned that COVID-19 has negative effects on project performance and reduced productivity for certain reasons. One important reason is employees were forced to stay away from each other and isolate themselves to avoid the spreading of infections. Sami Ur Rehman et al., (2022) informed that during COVID-19, the UAE construction industry faces several issues such as delays in revising schedules, disturbance of cashflow, delaying in permits, materials inspection and approvals, health and safety issues, shortage of material on site, and travel restriction that impact timely completion of projects. The UAE government and construction industry take initiatives such as providing support programs, digitalization of processes, implementing heavy fines, providing health facilities, and implementing new policies to reduce the impact of COVID-19 and improve the performance of projects. Khalef et al., (2022) mentioned that COVID-19 had a severe impact on the construction industry as well as other industries also. Shortage of materials, equipment, and human resources, and lack of project data negatively affect construction projects. The stakeholders should take early action on time and procure the materials timely to save from expected delays on projects. King et al., (2021) informed that Contractors were highly affected and faced several problems during the pandemic period. Contractors should improve existing strategies and policies to manage the performance of projects and contractors could better manage the problems. Nguyen et al., (2021) informed that during COVID-19, Vietnam's construction industry was highly affected and faced many challenges to completing the project on time and at cost. COVID-19 impact on multiple sectors as mentioned in Fig.1.

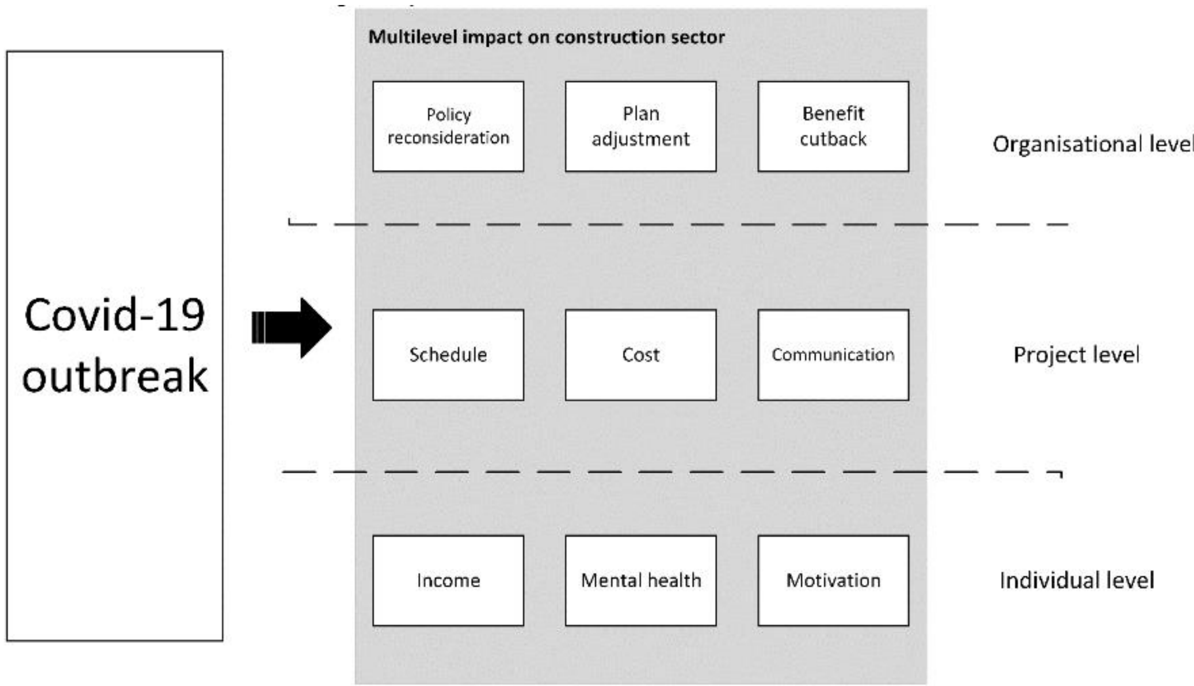


Fig. 1. Impact of COVID-19 on the construction sector (Nguyen et al., 2021)

Sohil et al., (2021) described that the overall world facing COVID-19 pandemic issues but those countries that have very low resources difficult to control it. During a small period, around 2.15 million people died across the world and 100 million were affected. The national command operation center (NCOC) of Pakistan identified that more than half a million suffered during the pandemic and eleven thousand were dead across the country Pakistan. For controlling that situation, the Government of Pakistan put a complete lockdown to control the spread of coronavirus as much as possible. Khan et al., (2022) mentioned that the COVID-19 Pandemic huge impact on the economy of Pakistan, and the construction sectors have been completely closed that affected and increase problems for employees/labor, especially for daily wagers. Increasing project time, re-mobilization of contractors, incomplete documents, and lack of e-communication channels were observed as major issues during the pandemic situation. The stakeholders should be equipped with the latest technology to manage and improve the performance of the projects even in a pandemic situation. According to Shaikh et al., (2021b), to acquire maximum effectiveness and efficiency, stakeholders should pay attention to rewards for high performance because the success and failure of workers depend upon the efficiency and effectiveness of the workforce at the workplace. Asghar et al., (2020) observed that COVID-19 hit Pakistan’s economy and paralyzed around 5 lacs people in Pakistan. The government of Pakistan announced relief packages to compensate lower-class labor and provide foodstuff for lower-class families for survival. The government should initiate to make new policies and strategies and provide a safe working environment for the re-mobilizing of workers.

2. Literature Review

As research discussed, project performance issues have been commonly observed during the COVID-19 period. COVID-19 affected on world construction industry including the construction industry of Pakistan. Timilsina et al., (2021) mentioned that COVID-19 highly impacts the construction industry of Nepal. The government of Nepal had a reduced financial budget for the construction industry which highly affected the contractor’s performance to complete the project on time. The government needs to build the mechanism and support the construction industry by revising of budget to manage and complete the projects on time. Once the issues have been taken on an early stage and discussed, the performance could be improved. Larasati et al., (2021) informed that during the COVID-19 period, contractors were mostly affected, and impacted cost performance as compared to other stakeholders. During the implementation of new procedures, contractors cover the extra cost implementing of health protocols. In that situation, the contractor faces financial problems to complete the remaining part of project in a short amount which affects the performance of the project. Stakeholders should revise the project budget to compensate the contractors that could complete the remaining part of the project. Pamidimukkala & Kermanshachi, (2021) mentioned that COVID-19 highly impact site and office working team in the construction industry. During COVID-19, project performance could be improved by increasing the level of information, stakeholders must educate the project force regarding new COVID-19 guidelines and procedures and make sure to implement them during work and maintain and establish an effective communication system. Al Amri & Marey-Pérez, (2020) informed that the construction industry of Oman was highly affected by COVID-19. All the major projects were delayed in completion because of travel restrictions and the supply of materials was a major issue due to the closed of borders. The worst economic condition of the construction industry impacted employees and stakeholders suffered to manage the operating cost.

Performance of projects can be observed by the completion of projects on estimated time and cost. Memon et al., (2021) informed that for successful measurement of the performance of projects, cost and time factors are basic parameters. Currently, the Construction industry facing poor performance issues due for several reasons. The high price of equipment, inconsistency in material price affecting cost performance and contractor financial problems, and incomplete project data affect project time performance. For improving time and cost performance, stakeholders should communicate and mitigates the issues that could help them improve project performance. Memon et al., (2019) mentioned that for the success of any project, time and cost is a key principle for measuring performance. Poor performances have been observed in Pakistan's construction industry. Communication, shortage of skilled personnel, and obtaining permits from government authority was major issue faced by a construction project in Pakistan. Soomro et al., (2019) conducted a study to identify time factors that affected building construction projects in Pakistan. Lack of contractor experience, contractor financial problems, change in scope during construction, and shortage of labor was observed main cause of time overrun in building projects. Stakeholders should control these factors through proper communication between stakeholders. Shaikh et al., (2021a) illustrated those positive relations between supervisors and workers create a positive environment through that employees can share their ideas, develop their skills and face challenges. Abdul Momeet, et,al (2022) mentioned that health and safety and environmental factor one of the important issues to impact the performance of projects. The unavailability of skilled staff was a major issue faced by stakeholders. Proper training should be provided to the staff to increase the level of information. Akhund & Memon, (2016) identified time overrun factors that affected construction projects in Sindh Pakistan. Issues in quality of works, incomplete project information, delivery of material, lack of communication system, working relationship between stakeholders, make changes in design and scope was observed as a major cause of time overrun in construction projects in Sindh. The factors could be controlled through remedial measures and effective communication, improving working relationships between stakeholders, procuring material on time, and providing complete project information could reduce the impact of time overrun. Akram et al., (2017) identified cost overrun factors that affected construction projects in Pakistan. Inflation in prices, increased project cost, delay in decisions, changes in design, inadequate planning, and scheduling, frequent changes in scope, inaccurate estimation, payment problems, and shortage of skilled labor were major factors causing project cost overrun. Timely decisions and frequent communication between stakeholders could reduce the impact of cost overruns of construction projects in Pakistan. Sohu et al., (2018) mentioned that cost overrun was one major problem for building construction projects in Sindh Pakistan. Increasing material pricing, incomplete project information, payment problems, poor site management, timely decision-making, and incomplete project information were observed as major factors that cause the cost overrun in the building project in Sindh. Shaikh et al., (2018) informed that for achieving target metrics, stakeholders focused on payment factors and time management which are creating a positive effect on productivity and enhancing innovation and create and help in solving critical problems.

This study conducts a detailed literature review on the performance of building construction projects in Pakistan. From extensive literature, this research identified the factors that frequently affected building construction projects in Sindh. From identified factors, this research highlighted important factors by conducting a quantitative method that could be helpful for contractors' firms to manage building projects smoothly during any expected pandemic period.

3. Aims and Objectives

This research aims to identify important factors that could support improving performance in building projects in Sindh even in a pandemic situation. The identified factors gave direction to all building construction stakeholders to take an early action plan to reduce the impact of a pandemic on running projects.

4. Methodology

An extensive literature review has been conducted to identify factors that normally affected the performance of building construction projects. A quantitative approach was used for the collection of data from respondents. This research focuses on the contractor sector because, during COVID-19, this sector was highly affected. A questionnaire survey form was designed based on the contractor's perspective and chose the factors that most affected building construction projects. Questionnaire survey form was distributed among employees working with contractor firms in building projects in Sindh Pakistan. The purpose of the study is to approach and collect data from those employees who suffer and have experienced managing the performance of projects during the COVID-19 period. The employees requested to choose important factors that could be beneficial for the contractors' firms and the contractors could improve their performance by using chosen factors even during the pandemic period. Received questionnaires survey forms analyzed through the Average Index Method because the Average Index Method is very popular in analyzing data for research works. The result and suggestion could help the building contractors of Sindh to include factors in the contract clause that could be used in an expected pandemic situation to reduce the impact of COVID-19 on building projects in Sindh Pakistan. The methodology chart has provided in fig – 2.

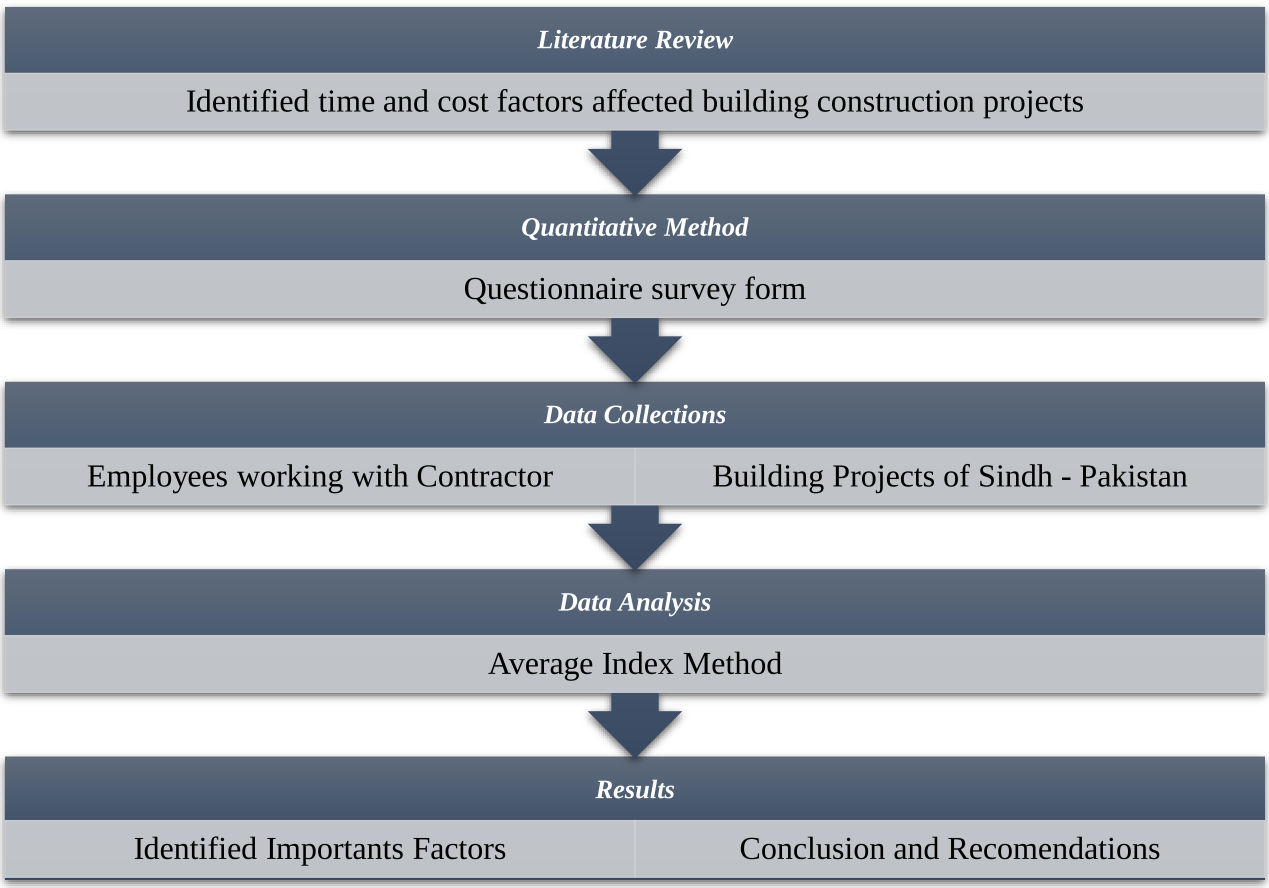


Fig. 2. Methodology Chart

5. Data Collection

A total of 110 questionnaire survey form has been sent to different employees working with different contractors' firm around building projects in Sindh. Mostly mega building projects are constructed in major cities of Sindh such as Karachi and Hyderabad. Ashraf et al., (2022) informed that Karachi city is the biggest city in Sindh -Pakistan and has around 16 million of population. Multiple mega projects are running in the city of Karachi to provide basic facilities for citizens. Out of 110 questionnaire survey forms, 93 questionnaire survey form has been received from the respondent; the majority was from building projects in Karachi Sindh. Received survey forms were analyzed through the average index method. A five Likert scale was used as 1 = Not Important; 2 = Slightly Important; 3 = Moderately Important; 4 = Important; 5 = Highly Important. AI is calculated by using the following formula.

AI = ∑ (1X1 + 2X2 + 3X3 + 4X4 + 5X5

Where, ∑ (X1 + X2 + X3 + X4 + X5) X1 = Number of respondents on a scale of 1 X2 = Number of respondents on a scale of 2 X3 = Number of respondents on a scale of 3 X4 = Number of respondents on a scale of 4 X5 = Number of respondents on a scale of 5	Evaluation ranges to assess Important levels, 1.00 < AI < 1.50: Not Important. 1.50 < AI < 2.50: Slightly Important 2.50 < AI < 3.50: Moderately Important 3.50 < AI < 4.50: Important 4.50 < AI < 5.00: High Important

6. Results and Discussion

A total of ninety-three questionnaire survey form has been received from different categories of employees having different years of experience. A questionnaire survey form was reviewed and analyzed to get the outcome of the research. Those factors having AI more than 3.5 has been considered for this research.

6. 1 Respondent Year of Experience

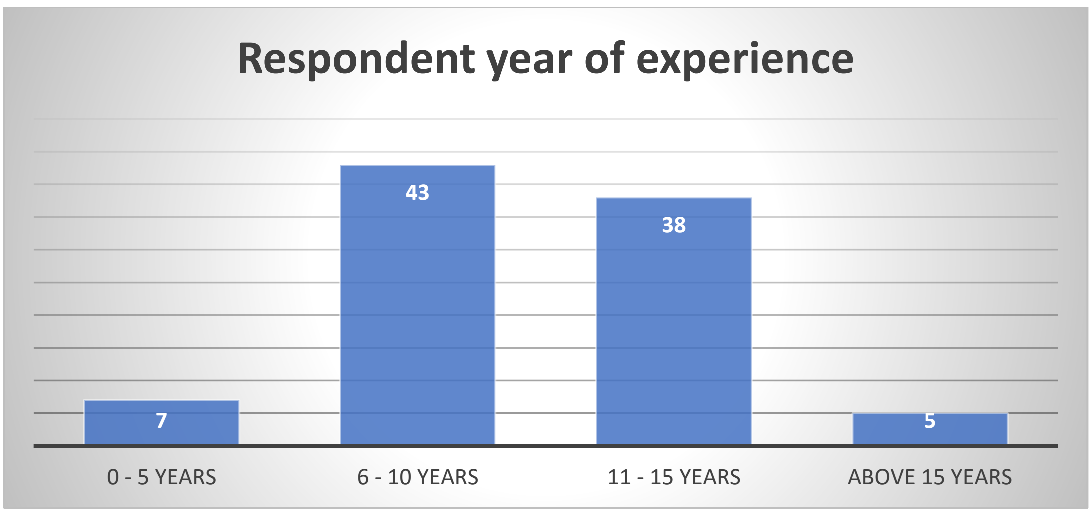


Fig. 3. Respondent year of experience

Figure 3 shows the respondents' total years of experience working in contractor firms. 7 respondents have working experience between 0 – 5 years, 43 respondents have working experiences between 6 – 10 years, 38 respondents have working experiences of 11 – 15 years, and 5 respondents have working experience of more than 15 years.

6. 2 Factors Improving Performance of Building Project

Extensive literature identified seventeen important factors that affected the performance of building projects. Out of seventeen factors, most of the respondents choose seven factors that could help to improve the performance of building projects during the pandemic situation. Figure 4 shows seven important factors (1) Providing a safe environment, (2) Revising the project budget, (3) Centralizing project data, (4) E-Communication, (5) Timely payment, (6) Extension of time, and (7) Timely decision-making.

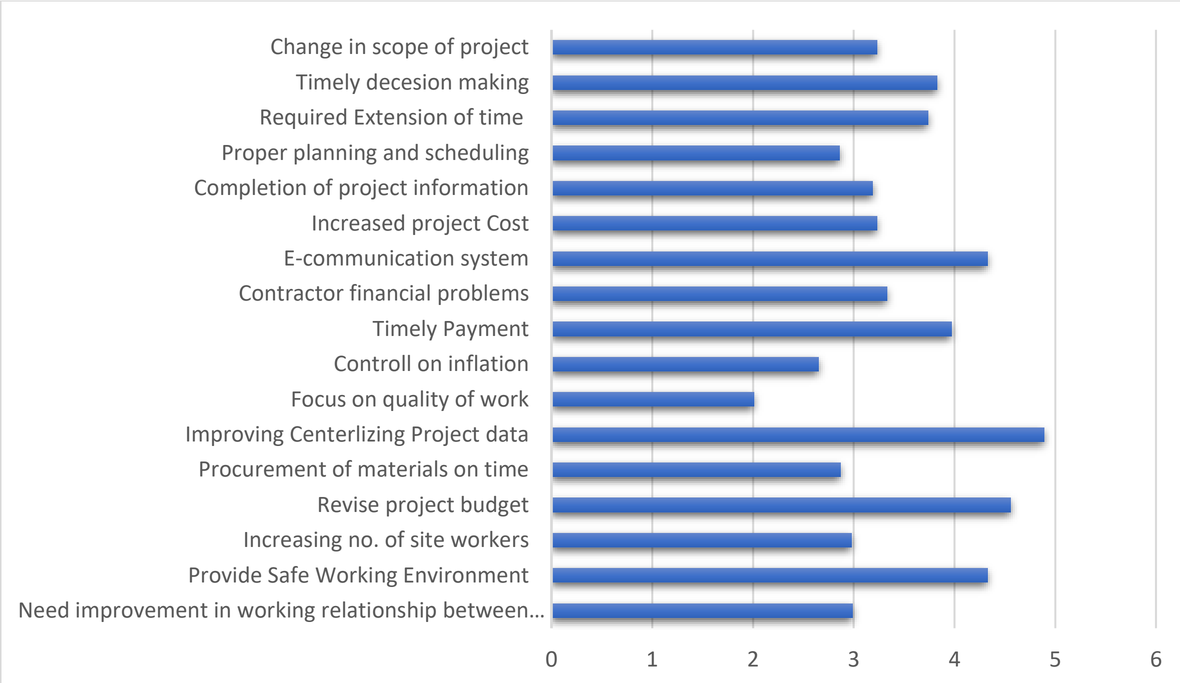


Fig. 4. Factors improving performance.

6.2.1 Provide a Safe Environment

A safe working environment was a top priority during the pandemic situation. Most employees prefer working remotely from home, and site management including the team could not perform and be stuck during the lockdown. After post-pandemic, the government and construction stakeholders decided to re-mobilization of work during the pandemic by implementing new policies and providing a safe working environment. Hussain et al., (2021) mentioned that construction stakeholders should design the plan and working procedures and implement them on projects. If the contractor provides a safe working environment, it could support employees to improve performance during working in the pandemic and the project could complete on time.

In addition, contractor firms should take precautionary measures on-site as well as office, by providing health and safety kits, working at a social distance, providing masks at the entrance of each door, providing hand sanitizing, and maintaining proper cleaning of offices and sites to smoothly completion of projects even in the pandemic period.

6.2.2 Revise Project Budget

Coronavirus highly damages Pakistan's economy. Pakistan's construction industry was on its way to improving and managing projects timely. But suddenly restrictions and implementation completed lockdown across the country; the Pakistan government deducted/reduce/cut the financial budget of construction that highly affected building projects in Sindh and resulting in all building projects have been frozen and delayed in completion. Larasati et al., (2021) informed that for re-mobilizing of contractors and projects, the client should revise the project budget to provide a safe zone for contractors to complete the remaining part of a project that was affected during the pandemic. Contractors mostly cover their budget for implementing health protocols at project sites. The responsibility of the government/client provides or revise the project budget that could support all contractor firms to the early completion of the project.

6.2.3 Centralizing Project Data

Centralizing data is one of the key elements of managing the information in any project. During the peak period of COVID-19, employees working remotely highly suffer from missing project data. Unexpected situation and complete lockdown during COVID-19, all employees were allowed work from home which affect performance. From the pandemic experience period, the contractor should upgrade, update, and centralize project data that every single employee could access remotely with implement data privacy rules and regulations. Khahro et al., (2020) mentioned that without centralized project data and information, a good project management activity will no longer exist. For managing the projects during the pandemic period if data is centralized it could support the improving performance of projects.

By centralizing project data, the performance of the project could be monitored, and contractors could take early steps to improve the timely completion of projects.

6.2.4 E – Communication

For the success of any project, communication is an important tool for the completion of the project on time. During COVID-19, communication was observed regarding sewer issues between employees and stakeholders. Lack of communication and tools affected contractor work and performance of building projects during a pandemic. Most contractor firms suffer during the pandemic by not properly communicating with clients and consultant team members regarding project progress. Pamidimukkala & Kermanshachi, (2021) informed that an important approach during a pandemic for site and office team workers should adopt proper communication through various tools. Most of the problems could be resolved through timely communication between stakeholders. Khahro et al., (2020) advised that several tools could be helpful during a pandemic for employees for managing the performance of projects, such as teams' meetings, emails, skype, zoom meetings, what's up, Imo, and facetime.

E-Communication could be suitable for employees working remotely managing the project's progress smoothly. Timely communication and resolving issues could improve the performance of projects even during the pandemic period. It's the responsibility of contractors upgrades the e-communication system, so every single employee could communicate frequently.

6.2.5 Timely Payment

Contractor firms mostly faced payments issues, and delays from the Client. Due to the economic crisis of COVID-19, construction stakeholders face a shortage of funds, especially contractors. Most funds have been used to control the spread of COVID-19. The client could not pay the contractor invoices timely which affects performance on projects. Timilsina et al., (2021) mentioned that late payment problems faced by contractors cause overrun costs of the projects. The client makes ensures timely payment to contractor firms to reduce the impact of cost overrun of projects.

6.2.6 Extension of Time (EOT)

COVID-19 highly impacted construction projects around the world including Pakistan building projects. During lockdowns and restrictions, building projects in Pakistan suffer increasing project costs and time. King et al., (2021) suggested that the client must provide an Extension of time to contractor firms, to complete the remaining parts of a project that affect and delay due to the lockdown. The revised schedule submitted by contractors mentioning a new finishing date due to a delay that is not the contractor's fault should be reviewed and approved by the Client and Consultant timely to support the contractor to finish the project smoothly.

6.2.7 Timely Decision Making

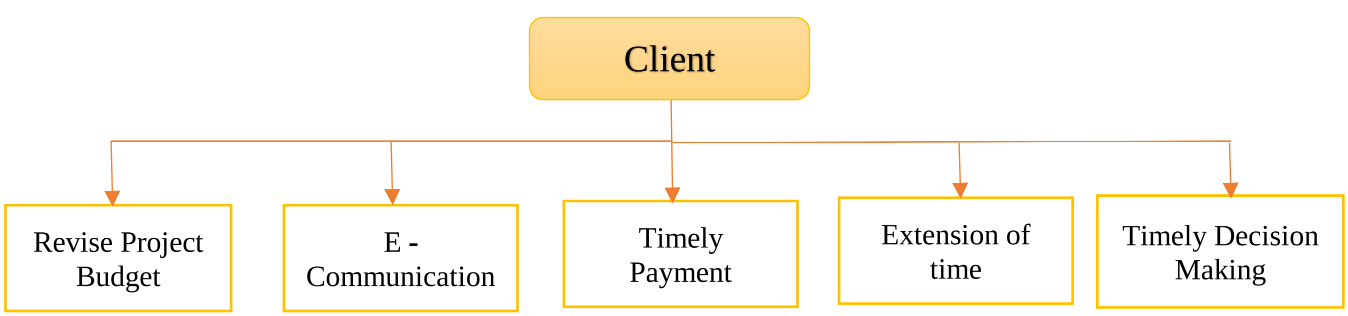
Timely decision-making is very important for the success of any construction project. In the construction industry, stakeholders must take early, jointly, and right decisions on time that could help in the completion of the project successfully. Taking wrong decisions could create several causes in terms of cost, time, and relationships between the stakeholders. During COVID-19, construction stakeholders were forced by the government to shut down their activities and were not able to take decisions, on how to manage the employees and the performance of projects. Shabbar et al., (2017) mentioned that making slow decisions from the Client affects the performance of projects. Dastyar et al., (2018) suggested that timely decision-making on different occasions of the project could improve the performance of projects.

7. Factors Related with Stakeholders

The identified factors from this research have relate with stakeholders mentioned and describe:

7.1 Factors Related with Client

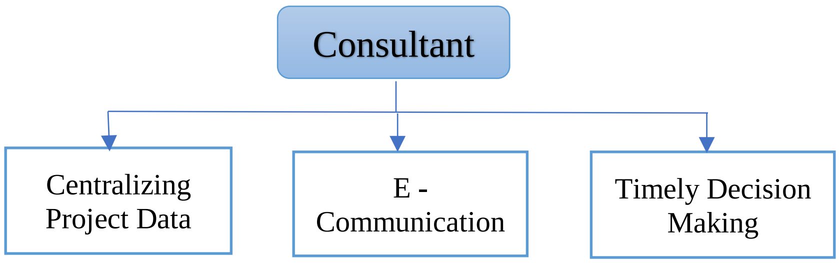
There were multiple factors related with client that client need to focus during pandemic could support the contractors to improve building project performance.



It has been suggested that during any expected pandemic situation, client should support the contractor to revise the project budget to manage the pandemic situation, provide extension of time to complete remaining part of project, and timely payment to contractors that could allow contractor to manage the project smoothly, contact all stakeholders through e – communication to be update about the project status, and support in timely decision-making to improve the performance of projects.

7.2 Factors Related with Consultant

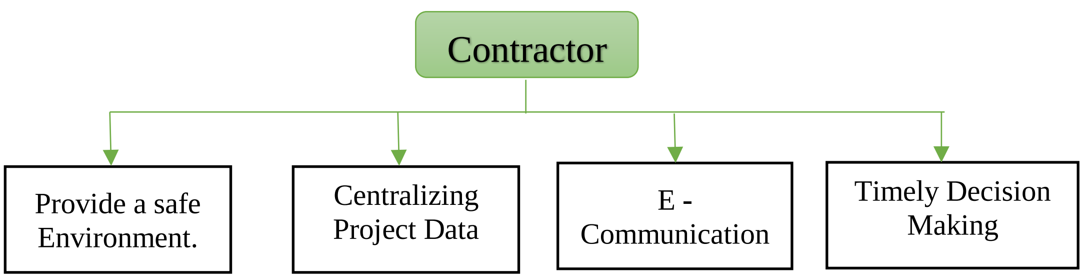
There were some factors related to consultant that consultant need to focus during pandemic could support the contractors to improve building project performance.



It has been suggested that during any expected pandemic situation, consultant should support the contractor to centralizing the project data that every one could have access remotely, contact with client and contractors through e – communication such as teams application, Zoom application, WhatsApp, and emails to easily exchange of information to discuss about the project progress, and provide support in timely decisions to improve the performance of projects.

7.3 Factors Related with Contractor

There were multiple factors related to contractor that contractor need to focus during pandemic could support the contractors to improve building project performance.



It has bee suggested that during any expected pandemic situation, contractor should provide a safe working environment for all employees and workers that every employee should feel safe and secure during working in pandemic period, project data should be centralized and easily accessible for all employee to update the project progress accordingly, contractor should communicate with their employees, consultant and client through e-communication channels to be update about the project progress, and contractor should take timely decision to reduce the impact of pandemic during construction and it could improve the performance of projects.

8. Conclusion

Construction projects in Pakistan highly suffered during the pandemic especially building projects in Sindh. Construction stakeholders could not bear the burden of lockdown and closing of projects, and its impact on performance efficiency. During the reopening of construction projects, many contractors suffer re-mobilizing of building projects and face financial crises. This paper examines important factors that could be helpful for contractors to carry out construction activities during a pandemic by implementing and including new factors in the contract clause; safe working environment, revising project budget, centralizing project data, e-communication, Timely payment, Extension of time, and Timely decision making. This paper advises contractors and clients who should include the above factors during signing the contract for managing the projects even during the expected pandemic period. Implementation of new policies and procedures could be helpful for a contractor to smoothly finish projects during a pandemic situation.

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Prerequisites for Achieving Value for Money in the Eastern Cape Department of Transports' Roads Infrastructure Projects

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Abstract
Ever-increasing service delivery protests resulting from poor or lack of service delivery and undesirable quality of workmanship of the Built Environment projects implemented in the public service adversely impact South Africa's overall economic performance, particularly the Eastern Cape (EC) Province. This paper aims to uncover areas that need improvements regarding the EC Department of Transport (DoT) getting value for Money (VfM) in procuring and delivering road infrastructure projects in the Eastern Cape Province. This study employed the qualitative approach. Twenty-five (25) semi-structured interviews were conducted with working professionals from EC DoT over Zoom and Microsoft Teams. Existing studies reflect two needful requisites for ensuring effectiveness and efficiency in infrastructure service delivery; these are 1) availability of resources and 2) a skilled workforce. The study's findings reveal that in ensuring VfM, the lack of monetary resources due to department budget cuts, hiring of unsuitably qualified contractors, corruption, and length of procurement processes require adequate resolution. These bottlenecks mentioned above to VfM cause significant delays in road projects. Contributions to achieving VfM thus includes include the appointment of competent personnel, and suitably qualified contractors, alleviation of corruption, and shortening lengthy equipment procurement processes. The need for seamless, integrated planning within the infrastructure service departments is also a prerequisite for achieving VfM.

Keywords
Client, Construction, Contractor, Road, Value for Money

1. Introduction
Construction remains a crucial sector of the national economy for countries worldwide [1]. Traditionally the construction sector comprises a significant portion of the nation's total employment and substantially contributes to its revenue as a whole [2]. South Africa's constitution provides for the mandatory delivery of adequate transport infrastructure. In South Africa's public sector, however, there remain visible disproportions between resourcing and productivity which adversely impact service delivery [3]. Ever-increasing service delivery protests continue to result from the poor or lack of service delivery and undesirable quality of workmanship of Built Environment projects implemented in the public service [4]. These adversely impact South Africa's overall economic performance, particularly the Eastern Cape (EC) Province, which remains infamous for road infrastructure backlogs spanning three thousand kilometers [5]. Therefore, resolving the road infrastructure backlogs requires effective and efficient methods to ensure good service delivery and Value for Money (VfM) [6]. Within any working environment, effectiveness and efficiency largely depend on the caliber of the workforce, their work ethic, professional experience, qualifications, the availability of sufficient resources, and the efficient use of those resources [7]. It also involves taking stringent

measures against corruption, hiring unsuitably qualified personnel for in-house positions, and outsourcing unsuitably skilled private contractors for bribes [8]. The issue of lengthy procurement times for replacing broken-down machinery parts such as grader tyres, for example, is another issue that requires attention if VfM in road service delivery is to be improved [9].

The EC-DoT employs three service delivery methods in delivering road infrastructure; outsourcing, in-house teams, and service-level agreements with other entities; the employment or utilisation of any of these three delivery methods in rendering road infrastructure must ensure that VfM is achieved [10]. VfM requires that existing resources at the disposal of the EC-DoT be used efficiently, as demonstrated by the private sector, to ensure that resource input provides maximum output [11]. When interrogating VfM, it remains vital to calculate the cost of goods and services; it also considers the combination of quality, cost, resources used, fitness for purpose, timeliness, and convenience to determine whether or not excellent value is achieved [12]. The utility of this study lies in uncovering areas in road service delivery that require improvement to ensure VfM. Within international research, this study contributes to existing literature that interrogates VfM in transport infrastructure planning, construction and maintenance. However, most international studies deal with VfM in the construction phases alone. Furthermore, with the dearth of literature regarding VfM achievement in road infrastructure service delivery, this study contributes to non-extant literature on VfM in South Africa’s provinces. It is the first study to undertake VfM in road infrastructure delivery across all project phases (planning, design, construction and maintenance) in South Africa.

2. Methods

This study employs Saunders’s research onion ring to ensure a systematic research process in undertaking this investigation [23]. This study is heavily influenced by the interpretive research philosophy, employs the inductive approach, adopts the single case study strategy, and utilises the qualitative method as a mono-method of data collection [24]. The qualitative approach was primarily chosen because it is predominantly associated with the interpretive philosophical paradigm [25]. The most common data collection method used in qualitative research are interviews and focus groups thus, a qualitative research approach based on an interview research design was adopted to conduct this empirical study [26].

The sample stratum of this study was limited to working professionals within the public sector, namely the EC-DoT's transport infrastructure unit. Working professionals were selected based on prior experience in road service delivery projects and more than one year of working experience within the EC-DoT. This was ensured to uncover the multifaceted perspectives of the built environment professionals regarding their experience in road service delivery. The sampling technique was purposive in that the questions formulated in the interview schedule were designed and distributed to a specific set of professionals relevant to the selected case study. Semi-structured interview questions were drafted to capture professionals' views based on their experience in road service delivery in the EC-DoT. With the EC-DoT’s permission, 25 respondents were contacted via email to solicit their willing participation. Twenty-five of the contacted respondents agreed to participate in the semi-structured interview willingly. The semi-structured interviews were then conducted remotely over Zoom and Microsoft Teams.

3. Results

The predominantly descriptive nature of the results presented in this study owes to the qualitative method applied in obtaining its primary data. Table 1 illustrates the number and percentage of professionals who willingly partook in the semi-structured interviews. Civil Engineers 84%. A Land Surveyor, Project Manager, Mechanical Engineer and Geotechnical Engineer represented the remaining 16% *of* willing participants. The years of experience of each respondent were captured and averaged at least ten years within EC DoT, reflecting their requisite experience to appropriately respond to the interview questions.

Table 1. Number and percentage of interviewed EC DoT professionals

Profession	Response	Percentage (%)
Civil Engineer	21	84.0
Mechanical engineer	1	4.0
Land Surveyor	1	4.0
Geotechnical Engineer	1	4.0
Project Management	1	4.0

According to Connelly [19], the merit of collecting and presenting demographic data to describe the people or organisations who form part of a research inquiry is critical for a study. The importance of collecting demographic data of interview respondents serves as proof that the data was collected and provides some form of validity, indicating that the interviews took place. Moreover, attributes such as gender, age, race, years of experience, and highest qualifications are provided from the respondents' demographic data from the EC DoT. The majority of the respondents were black males and black females, while white males, white females and mixed-race participation were much less in comparison. All respondents possessed a form of post-secondary school qualification, with the highest qualification being Masters's Degree. Also, regarding years of work experience, the respondent's answers indicated that they all had worked in the EC DoT for two years or more, having involvement in road infrastructure-related projects. The respondents thus possessed the requisite experience and qualifications to answer the questions in the interview schedule. A pie chart showing the percentage of various qualifications held by respondents is illustrated in Figure 1.

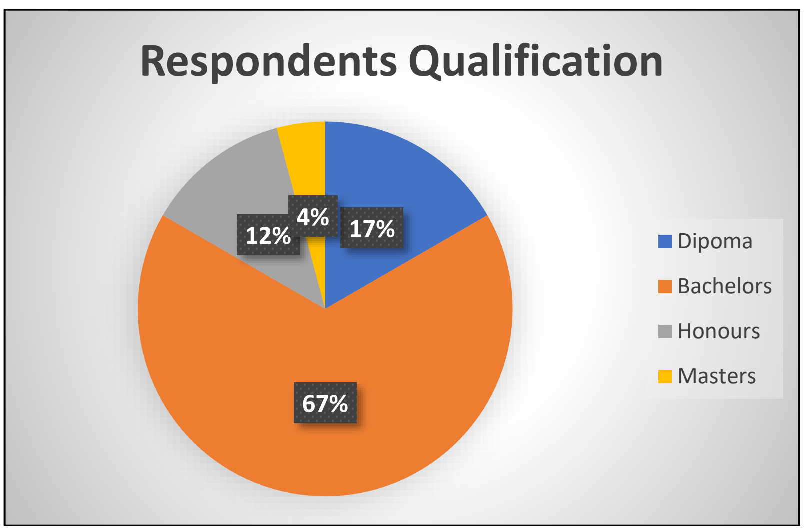

Figure 1. EC DoT Respondents' qualification composition

4. Discussion

From the interviews conducted and information from existing literature, it is apparent that the existing structure of the EC DoT is well-thought-out, with the necessary support structures required to ensure cost-effective service delivery. The programs and their various sub-units are geared to ensure that the implementation of services is within budget and in line with stipulations from existing guidelines. The delays in newly constructed roads infrastructure, existing roads maintenance and upgrades began with budget constraints which the EC DoT has experienced due to imposed budget cuts and limited funding [20]. The budget cut hindrances relate somewhat to the findings of [15], which indicate the importance of fiscal efficiency and discounted rates in ensuring successful infrastructure service delivery. Respondents also mentioned the cost of delays, the cost of unsuitably qualified personnel or competent service providers, and the need for more availability of resources or finance as additional VfM bottlenecks. The aforementioned factors were also mentioned in the literature review (section 2) by Malek [11], Sanni-Anibire, Mohamad Zin and Olatunji [17] and Park, lee and Kim [15]. All respondents mentioned project delays as the leading cause of project cost escalations at the planning, design, construction and maintenance stages. One example of uncertainty was when a road project was earmarked for completion within 24-36 months but took ten years. Apart from previously mentioned hindrances to VfM achievement, such as lack of finances and appointment of unsuitably qualified, other conditions in the EC Dot include slow procurement of damaged machinery parts, such as replacement of a grader's punctured tyres. Ameyaw, Adjei-Kumi and Owusu-Manu [20] Gave indications of the detrimental effects of project delays on VfM.

Additionally, in corruption, money allocated to undertake road projects used to pay bribes leads to an insufficient budget, thus reflecting fiscal and contract management incompetence [15]. Sufficient funding leads to either an incomplete or complete project with cost overruns or a compromise on project quality. Other causes of road project delays result from the illegal occupation (squatting) in areas earmarked for road construction. In instances of unlawful occupations, tensions among the illegal occupants. Another cause of contention mentioned by the respondents is the use of burrow pits within the boundaries of specific communities. In the case of the EC DoT, other arguments involving communities include socio-political interferences in projects and protests, all of which contribute to road service delivery delays [18, 19]. With the recorded dwindling of experienced professionals in-house due to their exeunt from the industry and entry into their retirement, the transference of skills from experienced professionals to emerging professionals remains essential. In addition, there must be an effort to ensure that the recruitment of in-house professionals have suitable qualifications and work experience per the job position’s requirements. Also, existing in-house professionals must upgrade their capabilities. Professional registrations, skills and job competencies by attending local and international workshops, conferences, and other upskilling activities.

The first limitation encountered was the need for more existing studies dealing specifically with VfM in EC DoTs road service delivery initiatives. Existing literature dealt primarily with the housing backlogs in the EC DoT, for which information existed in existing scholarly studies. Further developments in infrastructure service delivery, especially roads, needs to be more varied and requires extensive interrogations from various perspectives of public and private service providers and service users. Another limitation was that this study was primarily based on a qualitative research design. The use of quantitative data could have enhanced the robustness of the study; however the use of qualitative research design allowed for an in-depth understanding of the current state of VfM in EC DoTs roads infrastructure delivery in the EC. Another limitation of the study is that, as a single case study, its focus is on the EC DoT in the EC province. Future studies could focus on interrogating VfM in road service delivery in other areas such as the Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga, Northern Cape, North West and Western Cape. The case of contentions regarding borrow pit use is another area worth investigating: communities’ perspectives on using their borrow pits.

To uncover the requirement for ensuring VfM in EC DoT road service delivery projects within the EC DoT, it was necessary to first find out factors impacting the effective and efficient delivery of roads during the infrastructure design, construction and maintenance phases. Table 2, therefore, illustrates the existing factors that impede road delivery as per the perceptions of the various interviewees. The perceptions regarding VfM bottlenecks are recorded in the table. Overall the general perception within the EC DoT is that the department is only achieving an average of 50% of its potential in delivering road services due to the presence of the intersecting factors.

Table 2. Factors impacting VFM in roads service delivery

Stages	**Factors**				
	Budget cuts	Hiring unsuitably qualified - in-house	Corruption	Service delivery protests	Lack of community compliance
Infrastructure Planning	√	√			
Infrastructure design	√	√	√		
Infrastructure Construction	√	√	√	√	√
Infrastructure Maintenance	√			√	√

The results from Table 2 indicate that all respondents from the various sub-units of the road infrastructure department indicated that the most predominant factor hindering the successful delivery of road services are due to budget cuts. The second-most discussed theme was the issue of hiring unqualified or unsuitably qualified personnel in-house. It was emphasised by the respective respondents the importance of having both a suitable qualification and certain years of experience, thus covering the theoretical and practical demands of their respective road service delivery functions and duties. In conjunction with the topic of in-house staff is the mirroring issue of hiring unqualified contractors, which fits within the ambit of corrupt activity. As an in-house staff, contractors should also possess the required work experience and qualifications for their respective positions.

5. Conclusions

This study's primary aim was to uncover areas to determine if the EC DoT obtains VfM from procured road infrastructure in the Eastern Cape Province. Both primary and secondary data reveal that the EC province experiences the most severe backlogs regarding road infrastructure service delivery in South Africa. The backlogs result from budget cuts to EC DoT project funds, lengthy procurement processes due to red tape, especially when procuring machinery parts during construction or maintenance phases, and inefficiency regarding the use of in-house resources compared to the private sector that can ensure optimum output. Moving towards a solution-oriented approach for resolving the backlog involves hiring and contracting suitably qualified and competent in-house personnel and contractors. Procuring resources such as machinery or damaged parts must be undertaken as quickly as possible by reducing red tape if VfM in road services is to ensue.

Further studies within the confines of road service delivery in the EC DoT need qualitative and quantitative comparisons between the private and public sectors regarding effectiveness and efficiency in road infrastructure service delivery. Future studies could include the perspective of private contractors and service beneficiaries using quantitative surveys to obtain their views of the EC DoT roads service delivery performance. The target should be a larger and more comprehensive sample size hence the suggestion of questionnaire survey use. The perspectives of in-house professionals can then be compared to the views of various private contractors and existing literature to achieve triangulation of results to provide further rigour to the recommended study. Future studies could seek to develop a framework that promotes skills transfer from senior professionals, retiring or retired professionals to inculcate VfM practices among junior EC DoT professionals. Practice recommendations include the involvement or intervention of third parties in the tendering process to ensure that personnel can provide necessary services. Also, hiring suitably qualified in-house personnel must have a third-party intervention. Third parties in outsourcing and in-house recruitment will ensure the alleviation of bias and hiring based on favourites and pre-determined outcomes before interviews or tendering processes. Secondly, regarding corruption, stringent measures must be taken, and repercussions should exist for professionals engaged in corrupt activity.

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Stakeholder Power and Mutual Dependence: Construction Contractors are caught in an Economic Vise

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Abstract

This paper asserts that construction contractors are caught in a little understood dynamic of rapidly changing construction industry value each quarter. Chaotic work acquisition volume is the start of other follow-on problems that may lead to financial distress. Unpredictable construction volume at the local level causes negotiating power and mutual dependence imbalances that manifest in misaligned tenders and, thus, suboptimal contract agreements for contractors – main and sub. Tendering is the leading source of insolvency for contractors in Australia. At the same time, the number of competitors stays the same and the means of production – their trust and qualified people – are the last resort in cost cutting. Since net profit margins in construction contracting are single digit percentages, these firms are never far from producing a year-end financial loss. Additional pressures on contractors include a disproportionately high number of competitors when compared to established industries such as manufacturing. Construction material suppliers are few, so they control the flow of necessary materials for project installation while having the ability to limit credit amounts and penalise late payments via an adverse public report. These negative dynamics are exacerbated by uncertain workflow and cash flow. This paper asserts that contractors should develop more risk management strategies for the work acquisition function. We suggest some, such as the Developer-Contractor business model and structured decision-making systems. For society, the long-term critical need is for better organisational and project outcomes. These are critical for mitigating the emerging crisis of climate change effects and rapid urbanisation.

Keywords

construction industry, contractor payment, finance, contract terms, procurement, economics

1 Introduction

This research found a gap in the literature concerning the dynamics between stakeholders: owners/construction service buyers, contractors, and vendors/employees. This study's aim is to theorise that quarterly changes in construction volume facilitate significant power and mutual dependence imbalances to the other two groups that substantially affect construction contractors' performance, including insolvency. Furthermore, this is the leading cause of contractor bankruptcy. This paper uses a narrative literature review and a thought experiment from researchers' industry experience as a starting point for assertions. Additionally, the research team asserts that the evidence will be discovered when follow-on research is conducted.

The industry struggles to improve within an environment of adversarial commercial competition (Gray and Hughes, 2009). The industry's symptoms include work acquisition forecasting opaqueness, tardy contractor and supplier procurement, design chaos, confrontational relationships, distrust, unfair risk allocation and reliance on small contractors. The negative factors are exacerbated by the low bid and craft nature of the industry (Gann and Salter 2000). This often implies the creation of a new supply chain for each project and short-term, discontinuous interfirm relationships (Briscoe and Dainty, 2005). Furthermore, The Electrical Trade Union of Australia (ETUA) Report (2015) states, "*While market forces play a part, there are other factors at play—the structure of the commercial construction sector, severe imbalances of power in contractual relationships, harsh, oppressive and unconscionable conduct, unlawful and criminal conduct and a growing culture of sharp business practices.*"

2 Literature Review

The construction industry is complicated in its processes. Critical functions include forecasting, planning, communicating, regulating, designing, manufacturing, constructing, and maintaining buildings and other structures. In addition, the sector embraces all built items, either vertical or horizontal challenging constructors with dramatically different projects (Ireland 2004). These present a significant daily test for industry practitioners attempting to develop sourcing strategies to maximise value for money from their supply chains. There is less similarity between vendors. All these businesses vary in practices and outputs, such as prices, terms, conditions, delivery timeliness, and credit policies (Cox and Ireland, 2002).

Construction demand is inherently chaotic. Dramatic fluctuations in construction outputs are normal at the local level. The World Bank (1984) researched several nations with varying levels of wealth and found that the variation of construction outputs was twice as random as manufacturing and the general economy. A similar study of the European Union by the United Nations (1976) concluded that the construction industry experienced more unpredictable business cycles than other economic sectors. The nature of construction demand and the supply-demand dynamics of construction products, equipment, management and labour cause these fluctuations.

Construction clients who do not always fully understand their present and future demands are often shocked by the higher-than-expected competitive and adversarial supply markets. As a result, they are prey to opportunistic behaviour from construction firms operating in tier one (Ireland 2004). Constructing shelter, infrastructure and processing facilities involves numerous complex tasks with minimal costs. However, many functions in a construction project consume significant time and expense. Even a minor mistake can require substantial costs to rectify. So, careful craft and management are required (Lu et al. 2013).

Porter (2004) states that the fundamentals of every industry's dynamics are affected by five forces. These five forces directly apply to the construction. See Table 1.

Table 1. Porter's (2004) Five Forces Adapted to the Construction Industry

Forces	Construction Industry Dynamics	Power Advantage & How It Manifests
Competitors	The rivalry of existing firms. The number of competitors relative to other sectors provides a hint of intensity. Construction has four times the competitors than manufacturers (ABS 2020). This service industry is perceived as abundantly available. It is based on in situ projects; therefore, travelling site crews can go to where the work is within reason, thus, increasing local competition.	Project Owners / Construction Service Buyers – downward pressure on tender pricing due to the threat of a new source of construction services.
Possible Entrants	The threat of new competitors. New entrants can erode the market share and profit margins. Experience is available to all employees. Construction has three times as many new entrants as manufacturing (ABS 2021). Due to their zero backlog, they tend to be aggressive in pricing and promises when it costs them nothing but a conversation with a client.	Project Owners / Construction Service Buyers –a constant or rising number of similar construction firms
Buyers	Those customers exchange dollars for the products and services the industry participants provide. Increases and decreases in the number of buyers and changes the supply-demand dynamic. The construction service buyers start the process with their vision and funds, which vary depending on their needs and wants. The primary enablers of new construction are the cost of money and local population growth. The buyers seek excellent economic value for this large-cost asset. They scrutinise the proposals for an extended period of time and seek many providers before committing. Sometimes, they have options such as doing nothing, self-performance or remodeling their existing structure.	Buyers or Contractors depend on the economy's activity – boom, recession, or average growth. See Figure 1.
Suppliers	Vendors transacting with the construction industry provide materials, software, contract services, equipment, tools and other essentials. Construction has few suppliers of each type, and they influence the industry more than contractors. Construction suppliers sell to a fragmented industry. Due to their three valuable services to manufacturers, they do not have to contend with many substitutes for their products or delivery services – credit management, salesforce production and inventory buffer (Stevens and Smolders 2023). As a result, their products are a critical part of their buyers' business.	Vendors or Contractors depending on the activity of the economy – boom, recession, or average growth

Substitutes	Those organisations can provide an acceptable replacement for the industry's product or service. This is a constant threat to all competitors and thus heightens the tension between buyers and sellers. There are few alternatives to constructing buildings and structures. One option is offsite construction manufacturing components such as modular building vendors and pre-fabricators such as kitchen and bathroom pod assemblers. Precast systems have crossed into construction types such as bridges, roads, parking garages and building frames.	Project Owners / Construction Service Buyers – downward pressure on tender pricing due to the threat of a new source of construction services. See Figure 1.

2.1 Construction Stakeholder Relationship Dynamics

Resource dependence theory asserts a unified view of power at the organisational level of analysis. Pfeffer and Salancik (1978) created an enduring model to analyse complex inter-organisation relationships. Piskorski and Casciaro (2004) asserted that changing power imbalance and mutual dependence affect any company's performance. Emerson's (1962) theory of power-dependence relationships and its exchange framework claims that the power capability of actor one concerning actor B is the inverse of A's dependence on B. In turn, dependence is a function of resource priorities and the number of alternative input providers. See Table 2. One explanation is that stakeholder A relies upon stakeholder B in proportion to A's resource requirement that B can provide and (2) in inverse proportion to the availability of alternative actors capable of offering the same input to A. Conversely, stakeholder B's needs on stakeholder A vary (1) in proportion to B's resource requirement that A can furnish and (2) inversely with the number of other stakeholders able to furnish the same inputs to B. See Table 2.

Power imbalance captures the dynamics of relationship independence of one actor over another. Their need for each other – typically asymmetrical explains a tendency to accommodate or reject demands. Formally, this construct can be defined as the difference between two actors' dependencies or the ratio of the negotiating leverage. During the legal contract phase versus the sales or post-transaction phase), power imbalance reduces the frequency of exchange among actors by hindering conflict resolution (Lawler and Yoon, 1996). A company with leverage advantages tends to argue for agreements favouring itself, whereas the weaker actor argues for agreements that equalise benefits. Unequal power manifests in issues of legitimacy and fairness concerning the distribution of benefits, complicating the bargaining agenda and diverting attention from the structural dependencies the exchange should address (Lawler and Yoon, 1996).

The second aspect of any business relationship is mutual dependence, which captures the existence of bilateral dependencies, regardless of whether balanced or imbalanced. Mathematically, this measure can be defined as a function of the two actors' interdependence (Bacharach and Lawler 1981).

Power imbalance and mutual dependence must be considered simultaneously to produce an identifiable power-dependence structure in any relationship. This is because, for any value of power imbalance, a power-dependence relation can be characterised by varying levels of mutual dependence. Conversely, for any given level of mutual dependence, there can be a range of power imbalances (Casciaro and Piskorski 2005). The power imbalance is at its highest – 2 – when low-dependence actors work with high-dependence ones. The lowest mutual dependence score is when two low-dependence parties work together. See Table 2.

Table 2: Adapted from Power Imbalance and Mutual Dependence Configuration Table (Casciaro and Piskorski 2005).

		Construction Stakeholder A's Dependence on Stakeholder B		
		Low	Medium	High
Construction Stakeholder B's Dependence on Stakeholder A	Low	Power Imbalance: 0 Mutual Dependence: 2	Power Imbalance: 1 Mutual Dependence: 3	Power Imbalance: 2 Mutual Dependence: 4
	Medium	Power Imbalance: 1 Mutual Dependence: 3	Power Imbalance: 0 Mutual Dependence: 4	Power Imbalance: 1 Mutual Dependence: 5
	High	Power Imbalance: 2 Mutual Dependence: 4	Power Imbalance: 1 Mutual Dependence: 5	Power Imbalance: 0 Mutual Dependence: 6

Porter (2004) provides an approach to view the construction industry regarding its threats and opportunities for its stakeholders. This paper has created an Australian Construction Industry Dynamics Table to clarify the disorder and relativistic characteristics of the industry. See Table 3.

Table 3. The Australian Construction Industry Dynamics Adapted from Porter (2004).

Porter's Dynamics	Construction Industry Description and Effect
Ease of entry	Construction contractors can quickly enter the business without requiring significant qualifications such as advanced education and extensive experience. Craft skill is not learned in a classroom but on-site and is the number one value construction firms provide to project owners.
Transaction size is large	Project cost is the most significant personal or top three corporate investments. The scrutiny of the purchase and the sizeable monthly billing leave contractors exposed to profit and cash flow shortfalls. Wild swings in turnover (revenue) are expected). See Figure 2.
Experience is available	Many field and office people gain a significant understanding of the construction process – technical and business - during employment. Many inputs (client, labour, material, equipment) are evident to them, including the process of work acquisition, project operations, and finance that creates project profitability. This leads employees with critical industry knowledge and insider understanding of their current employer if they venture into the market as a constructor.
Numerous and equally balanced competitors	In many markets, the highest market share of any firm is two per cent or less and over 95% are considered small and medium enterprises (SME) (ABS 2021).
Lack of differentiation	The plans and specifications determine the product. All companies share the people constructing it (can work for any of them). Construction knowledge is observable and shared widely due to high employee turnover (differentiation of a viewable service is complex)
Switching costs	There is little or no switching costs to engage a different construction company to build the next project. So, project owners have many options in their negotiation with a contractor.
Fragmentation	Fragmented industries are challenging for one company to dominate and thus consistently prosper, and more importantly, there are few holistic solutions to its problems. There are many reasons for fragmentation, including low entry barriers, absence of economies of scale, highly diverse market needs, local jurisdictions and erratic sales fluctuations. The largest construction companies in Australia do not dominate the market. For example, CIMIC's market share was 1.9%, whereas Lendlease earned less than 1.0% (IBISWorld 2022).

The most likely result of this power and low mutual dependence imbalance on the weaker party is that those with more leverage will appropriate more significant benefits from the confrontation or collaboration. As the power imbalance increases, the weaker-positioned organisation faces an increasingly dire negotiating position and less certainty. (Piskorski and Casciaro, 2004)

3 Methodology

This paper has applied the Power Imbalance and Mutual Dependence model as articulated by Piskorski and Casciaro (2004). Table 4 lists the three major stakeholder groups' abilities and potential actions affecting others in the typical construction project. The approach uses the researcher's experience in a thought experiment using accepted frameworks.

Table 4. Three Groups of Construction Stakeholder Abilities – Generally - to Affect Power Imbalance and Mutual Dependence

Stakeholder	**Abilities and Potential Actions**
Group 1 - Project Owners – public and private	They can entertain many proposals from providers based on non-standard information and select a contractor based on total cost or best value. Typically pay large monthly allotments subject to their contract interpretation, physical progress percentage perception and project specification interpretation. Normally, they can delay the project start date without penalty.

Group 2 - Contractors – Main and Trade	They rely on trade contractors to supply material, labour and equipment but are exposed to risk if the subcontractors have won more projects than they can effectively construct. Can bid on projects in other's locale due to lack of work in their area, thus raising competition. Projects often do not start on the proposed date for breaking ground. Many require government-enabled licensing or other qualifications to install their specific work. Their workers exercise at-will employment. Trade Contractors supply material, labour and equipment but are exposed to risk if the subcontractors have won more projects than they can effectively construct. Can bid on projects in other's locale due to lack of work in their area, thus raising competition. Often, project starts are delayed, translating into rushed completions where safety, quality, productivity and documentation suffer.
Group 3 - Labour and Management	Qualified Labour and Management is the most significant variable in construction; it influences project safety, quality and productivity. Its availability, lessening over the last decade, encourages managers, crafts persons and operators to be more selective of employers and pay rates. As a result, moving from company to company is more common now for less significant reasons than previously. Annually, the turnover of construction employees is over 100% due to the lessening availability of qualified personnel and dramatic fluctuations of demand in each region (Stevens 2022). See Figure 2.
Group 3 - Material Suppliers and Equipment Hire Organisations	They can directly set contractor pricing, purchasing power and the volume of orders through their credit functions. Also, they can report adverse payment activity by contractors. The availability of products and equipment is directly influenced by construction economic activity.

Economic activity changes the dynamics of commercial relationships. To illustrate, consider these extremes: recessionary versus high growth periods. See Figure 1.

In recessionary times, several characteristics emerge.

- *Group 1* - Project Owners and Construction Service Buyers can entertain many proposals from contractors and property owners to seek financially advantageous terms and conditions. They do not have to build, but the project can advance if the proposers offer great economic value (sometimes due to desperation).
- *Group 2* - Contractors (main and sub) seek to find many potential clients to propose to. As a result, they offer financially attractive tenders with significant concessions in terms and conditions. At the same time, they are reducing staff to decrease operating costs due to the lack of replacement projects for those closing.
- *Group 3* –
    - Labour (crafts persons, equipment operators and labourers) and Managers (Project, Site, and General Office seek work against many like-qualified applicants.
    - Material Suppliers and Equipment Hire Organisations are liquidating their inventory and equipment fleets to minimal viable levels and using the cash as a buffer against the downturn if it continues longer than expected.

In high-growth periods, these behaviours are common:

- *Group 1* - Project Owners and Construction Service Buyers design and fund projects that do not violate their money-for-value equation with fewer above-average profit opportunities. Speculative development occurs more often in economic booms, followed by recessions in local markets, leading to sometimes payment reductions and delays.
- *Group 2* - Contractors (main and sub) tender more projects than previously but are hard-pressed to reject an accepted proposal from a client. Their prices rise well past their recessionary proposals. As a result, they may overfill their "doable" backlog. Once their tender is accepted, they attempt to schedule not to overlap each excessively; however, the client's contract penalises untimely progress/.
- *Group 3* –
    - Labour (crafts persons, equipment operators and general labourers) and Managers (Project, Site and General Office) are carefully selecting whom to work for and at what wage, mindful of the excessive "lost last job" statistics (well over 100% is some years).
    - Material Suppliers and Equipment Hire Organisations propose higher unit prices and monthly hire rates. As a result, products and equipment may become scarce as inventories are managed aggressively to maximise profit opportunities.

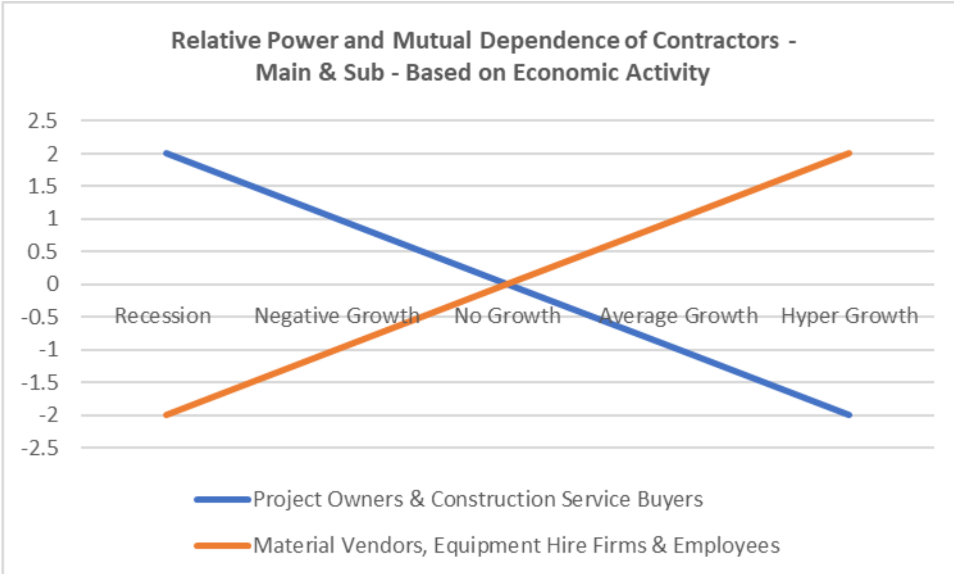

Figure 1. Power Imbalance and Mutual Dependence Per Economic Activity Cycle. Adapted from Casciaro and Piskorski (2005).

The researchers collected construction dollar value (ABS 2022) in the most recent 12 years available and calculated the percentage change for each quarter from the previous for four distinct construction subsectors – New Residential, Residential Remodeling, Non-Residential, and Engineering. In addition, four regions of Australia were selected - two most significant and two smallest by population – New South Wales (NSW), Victoria) VIC), Tasmania (Tas) and Northern Territory (NT). See Figure 2. This chart shows what the UN and World Bank concluded previously; a highly fluctuating construction volume at the state and territorial levels. See Figure 2.

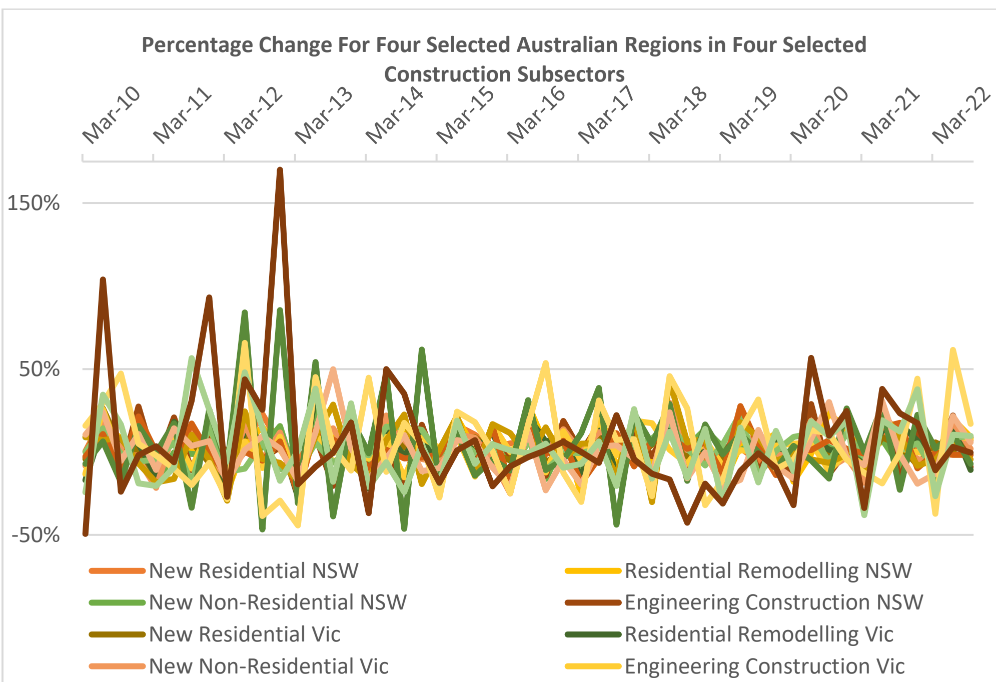

Figure 2: A Visual of Chaotic Construction Volume of Four Regions in Four Work Subsectors by Quarter from 2010 to 2022 (Source ABS 2022)

Figure 2 indicates tendering chaos at the regional, city and town level, where most contractors can efficiently operate. Upon analysis, the following results were found in 816 periods (51 quarters x 4 regions x 4 types of construction work). This output was compared to the previous quarter.

- There were 58 occasions of two-quarters of sequential decline (definition of an economic recession)
    - Of the 58 occasions – 28 were between 3 and 5 quarters.
- There were 427 quarters (52.3%) of negative or no growth.
    - 293 or 35.9% of the total were double-digit percentage declines.
- There were 323 quarters of double-digit percentage growth.

This unpredictability is considered normal, while construction contracting employment between 2017 and 2020 stayed steady at approximately 500,000 persons and organisations at 230,000 (ABS 2020). However, industry studies have shown that underbidding and tendering errors significantly contribute to construction contractor bankruptcy (Stevens and Piracha 2022). This is partially enabled by the nature of the tendering process, preferring low bids typically while incomplete plans and unclear details are considered the norm (Laryea 2011)

3.1 Suboptimal Results

Australian construction contractor insolvency rate (pre-COVID) averaged five years from 2021, was approximately 14.0% versus 11.1% for manufacturing (ABS 2021). The Australia Construction industry dynamics produce the highest percentage of business bankruptcies of all sectors and the most follow-on individual insolvencies. For the 2016-2017 fiscal year, construction entrepreneurs were the most common occupational category for debtors entering business-related bankruptcies (O'Brien et al. 2018). Murray and Harris (2016) found that follow-on individual insolvencies vary within different sectors of the economy. Still, built environment professionals represent the highest proportion of debtors entering business-related personal bankruptcy. Sadly, this group has a top-quartile percentage of domestic partners (O'Brien et al. 2018). For the year 2019-20 (the last pre-pandemic year), 16.8% of construction firms declared a financial loss (ABS 2022b)

4. Discussion

Economic spirits are different between expanding and contracting markets, i.e., behaviours change. This paper asserts that negotiating power and mutual dependence imbalances are evident between construction stakeholders, with contractors caught in the middle. Tendering is the start of the process but also the most problematic. The chaotic volume of the construction industry is one root cause of its problems. This generates negative cash flow, an existential threat. This "too hot, too cold, never just right" nature of workflow is shown in Figure 2. So, when practices are rushed (too hot), quality declines, resulting in expensive rework or is too cold; thus, multifactor productivity is suboptimal. Contrast this cashflow with the promise of paying hourly workers weekly and salary staff fortnightly. Also, the industry suffers from the "hurry up and wait" problem, i.e., starting later than initially planned. This means assets are committed but underutilised or not working on the project they are dedicated to. As a result, multifactor industry productivity has stagnated since 1998 (Stevens and Smolders 2023). Portfolio management is critical due to the single-digit net profit margins (Stevens 2022), and any dispute usually results in delayed payment.

Equipment hire yards and material distributors demand payment approximately 30 days after the month of billing. It is common knowledge that the best-paying organisations receive more on-site workers because progress billings are paid timelier. The construction industry has more risk than most. Insiders perceive it as having many uncontrollable factors. One sage contractor stated, "Do not name your company after yourself". You run the risk of hurting your family name. As is well known, bankruptcy is the inability to pay creditors under agreed terms and conditions. This occurs disproportionally higher in construction than in any other Australian industry (ABS 2021a)

Some Australian construction contractors have taken action. They have turned to another business model: the developer contractor. The two largest property companies in Australia, Lendlease and Meriton use this business approach. Others have instituted a multi-step process such as a go/no go bidding process, resource forecasting, dual rate costing, and target negotiated work as a "must do" strategic action. The actions lessen or eliminate the "one way" street of winning work that is low versus an average of both high and low.

5. Conclusion

The construction industry is essential to Australia's quality of life but chaotic in its creation process to the frustration of governments, private clients, the public and industry professionals. The sector is a complex behemoth that is highly fragmented with wildly fluctuating turnover locally. The industry leaders understand many of the dynamics shared, which may make for contrary and confronting strategies by each stakeholder to others.

Construction service buyers have significant leverage to enable industry change, particularly public project owners whose annual purchases are substantial. Governments should use investment funds to draw the industry's attention toward solutions utilising legislative and judiciary power. They can set improved systems and rules for the rest of the sector. Technological advances can be used in many ways to help contractors better manage tendering risk. Software developers should respond to this industry quickly in new directions due to the industry's size and profit opportunity.

The mix of pressures on the contractor, such as unpredictable revenue, cost accrual, small profit percentages, and a few sources (projects) of income, makes for complex stakeholder relationships and operational approaches. Additionally, relatively few suppliers control access to critical products with the ability to limit credit and report adverse payment information. As a result, the construction industry has a power imbalance; the largest appears to be centred on the contractor (main and sub). Yet, they are crucial to project success. Contractors are the design installers while stewarding safety, quality and productivity. The frameworks utilised, the type of data presented, and the conclusion appear to apply to other Western economies. Further research should be funded and pursued.

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Barriers to implementing GreenBIM in the construction industry: a developing country study

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Abstract

Overcoming the hurdles to achieving GreenBIM is critical to achieving its implementation. This is not an isolated case, as the construction industry is known to be slow to attain digital adoption due to various challenges. This study is important for identifying and overcoming the various barriers to achieving sustainability in the construction industry. The study collected randomly through well structured questionnaires. The collected data was analysed, and the study findings reveal, among others, that there is lack of GreenBIM guide, a lack of incentives to adopt GBIM, lack of BIM training, and business changes are some of the barriers to GBIM adoption in developing countries.

Keywords

GreenBIM, hurdles, sustainability

1. Introduction

The construction industry is actively adopting various innovations and technologies to improve industry products (Adekunle et al., 2021; Ejohwomu et al., 2021). Also, the adoption of these new approaches as opposed to the traditional methods is also beneficial to achieve sustainability and provide environmentally friendly construction industry products. Sometimes, these innovations and emerging technologies are adopted separately, while some are combined. The concept of Green Building information modelling(GreenBIM/GBIM) involves the fusion of green technology and Building information modelling(BIM). Although still a budding area as compared to BIM, it has been adopted in both large construction projects and residential buildings (Ekasanti et al., 2021), although not without shortcomings and areas for improvement.

Shukra & Zhou, (2021) viewed Green Building information Modelling as a concept that adapts green building and Building Information Modelling practices towards achieving a sustainable design and objectives in a construction project. For Liu and Wang, (2022), it involves a process of improving the building performance while creating and managing the lifecycle information using Building Information Modelling without compromising the achievement of the project goals. Akmal *et al.*, (2019) revealed the importance of combining green building and Building Information Modelling in the process of all phases of the project, including maintenance, renovation, and demolition, ensuring that the project results meet the standard of Green Building Information Modelling. This combination integrates sustainability and effective information management. Consequently, the importance of BIM in achieving GreenBIM cannot be overemphasised as it plays a critical role. GBIM, among other uses, provides for the reduction of waste, reduction of environmental impacts while improving quality, improves collaboration, and real-time information management, among others, as it fuses the advantages of green building and BIM. (Cassino et al., 2010) views GreenBIM as the adoption of BIM tools to achieve sustainability and improved building performance on a construction project. Basically, GreenBIM consists of three components, BIM, Green Building certification protocol and environmentally sustainable design(Gandhi & Jupp, 2013).

GreenBIM is used to achieve energy performance analysis, acoustic analysis, building performance analysis, carbon emission analyses, natural ventilation system analyses, solar radiation and lighting analyses, and water usage analyses, among others (Chang & Hsieh, 2020; Lu et al., 2017). Some other benefits of using BIM for sustainability practices in the built environment include achieving real-time sustainable design and multi-design alternatives and reduction of project environmental impact, among others (Olawumi & Chan, 2019).

Actualising these benefits has been difficult in the construction industry, especially in developing countries. This study aims to identify the barriers to implementing GreenBIM in the south African construction industry.

2. Barriers to Green BIM implementation

Despite the inherent benefits of the implementation of GBIM in the construction industry, achieving it has been a tedious task. This is due to the various barriers that have made it impossible. According to (Cassino et al., 2010), one of the challenges faced in the construction industry when it comes to the adoption of GreenBim is the lack of tools and the complexity of developed models. Some other barriers include lack of experts ((Akmal et al., 2019) (Sehrawy et al., 2021)), lack of knowledge (Akmal et al., 2019; Araszkiewicz, 2016), high implication cost (Araszkiewicz, 2016; Sehrawy et al., 2021; Zhabrinna et al., 2018), lack of GreenBIM awareness (Akmal et al., 2019), culture resistance (Adekunle et al., 2022; Sehrawy et al., 2021), lack of standard workflow (Sehrawy et al., 2021), deficient BIM libraries (Sehrawy et al., 2021) among others. Most of these barriers are context specific, hence the study to determine the barriers specific to the South African construction industry regarding GreenBIM implementation.

3. Research Methodology

This research was aimed at identifying the barriers to the implementation of GreenBIM in the construction industry. Construction industry professionals in the South African construction industry (architects, construction managers, Quantity surveyors, town planners, civil engineers, electrical engineers, mechanical engineers, and safety managers) were sampled. Sampling these professionals is essential due to the various roles they perform in the construction industry, especially in the era of innovations is considered very important. A quantitative approach was adopted through the use of well-structured questionnaires; this has been well adopted in built environment research to generalise outcomes (Akinradewo et al., 2022; Aliu & Ohis Aigbavboa, 2020) using numerical data. A total of sixty-four data was collected. The administered questionnaire adopted a five-point Likert scale to provide a quantitative measure (Boone & Boone, 2012). The five scales adopted are strongly disagree, disagree, Neutral, agree and strongly agree. Firstly the reliability of the items making up the scales was measured using the Cronbach Alpha. According to Pallant, (2010), the value range between 0 to 1, and good reliability should be above 0.7. the Cronbach alpha for this study achieved 0.949. This means the instrument measurement items are reliable. The data collected was analysed using the Mean item score and Kruskal Wallis H test. This is to determine the average of responses and differences in respondents opinions.

4. Research findings

4.1 Background information of respondents

The respondents for the study consist of 60% possessing bachelors degree, 20% of the respondents have diploma, 9.2% of the respondents have Masters degree, followed by 7.7% possessing Matric certificate and 1.5% having PhD. Table 1 also shows the profession of the respondents to be 33.8% Quantity surveyors, 21.5% construction managers, 16.9% electrical engineers, and 12.3% of the respondents are civil engineers. Other professions in the respondents are Architects (7.7%), Mechanical engineers (3.1%), safety managers and town planner (1.5% respectively). Respondents possess various degree of industry experience; the majority of the respondents have between 0 – 5 years (67.7%). Other respondents possess between 5- 10 years of experience (26.2%), 15-20 years (3.1%) and 1.5% possess experience above 20 years in the construction industry. Furthermore, the respondents are predominantly working with contracting organisations (32,3%), followed by those working with government parastatals (27.7%), 20% work with private organisations/clients, and 18.5% are consultants.

Table 1: Respondent background information

Highest educational qualification	Frequency	Percent
Matric certificate	5	7.7
Post certificate or Diploma	13	20

Bachelors degree	39	60
Masters degree	6	9.2
Doctorate	1	1.5
Profession		
Construction Manager	14	21.5
Quantity Surveyor	22	33.8
Town Planner	1	1.5
Civil Engineer	8	12.3
Electrical Engineer	11	16.9
Mechanical Engineer	2	3.1
Safety Manager	1	1.5
Architect	5	7.7
Years of experience		
0-5	44	67.7
05-10	17	26.2
15-20	2	3.1
More than 20 years	1	1.5
Institution/organisation		
Consultant	12	18.5
Government	18	27.7
Private Organisation	13	20
Contracting organisation	21	32.3
Familiarity with Green BIM		
Not at all familiar	13	21.5
Slightly familiar	16	24.6
Somewhat familiar	18	27.7
Moderate familiar	12	18.5
Extremely familiar	5	7.7

Meanwhile, it is worth noting that respondents are familiar, although to different degrees with the GreenBIM concept. Only 13% claim not to be familiar with the concept, and this study serves as a source of awareness to the professionals. It does mean the concept is fairly new in the South African construction industry.

4.2 Barriers to implementing GreenBIM

Table 2 presents the mean item score of each of the presented variables to the respondent. The mean item score was adopted to get the average of the responses collected from the industry professionals based on a five Likert scale. The table presents the variables and the MIS, and the SD. From the table, all variables presented are significant. However, according to the data collected, the most significant variable is the lack of a GreenBIM guide, with a score of 3.64; this is followed by a lack of incentives for promoting GreenBIM (MIS = 3.61). Other barriers to the implementation of GreenBIM include the lack of BIM training (3.56), business changes (3.55) and lack of BIM demand (3.53) and the lack of government support (3.47). The study also checked if there is a significant statistical difference in response based on the professionals grouping; the Kruskal-Wallis test (Table 3) was employed. According to (Pallant, 2010), a significance level of above .05 signifies that there is no statistically significant difference in the responses across the groups. For this study, all variables achieved a significant level above 0.05 except for the high implementation cost, which has a value of 0.019.

Table 2: Barriers to the implementation of GreenBIM

Barriers	Mean	Std. Deviation
Lack of Green Building Information Modelling guides	3.64	1.213
Lack of incentives for promoting Green Building Information Modelling	3.61	1.149
Lack of Building Information Modelling training	3.56	1.180
Business changes	3.55	1.053
Lack of Building Information Modelling demand	3.53	1.195
Lack of experts on Building Information Modelling	3.47	1.195
Lack of government support	3.47	1.247
Culture resistance	3.44	1.167
Shortage of skills	3.39	1.341
Lack of knowledge	3.39	1.280
High implementation costs	3.39	1.242

Table 3: KWH test for responses

	Kruskal-Wallis H	Asymp. Sig.
Lack of experts on Building Information Modelling	8.138	0.321
Lack of knowledge	11.901	0.104
High implementation costs	16.693	0.019
Lack of Green Building Information Modelling guides	6.445	0.489
Culture resistance	3.860	0.796
Lack of incentives for promoting Green Building Information Modelling	6.919	0.437
Lack of government support	6.848	0.445
Shortage of skills	12.960	0.073
Lack of Building Information Modelling training	11.413	0.122
Lack of Building Information Modelling demand	10.567	0.159
Business changes	7.615	0.368

The results suggest a lack of GreenBIM guides and structure, which can be linked to a lack of awareness, lack of legal structures necessary for implementation, and stakeholders not fully aware of the full benefits or how to implement GreenBIM among other factors. These factors are not isolated to GreenBIM implementation as they have been identified, especially lack of adequate awareness or clarity to be a critical barrier to the diffusion of technology and innovations in the construction industry (Adekunle et al., 2020; Akinradewo et al., 2022; Ikuabe et al., 2022; John et al., 2022). This might also be a likely reason for the diverse ranking of the high cost of implementation by the respondents, as they might not have full clarity on the implementation of GreenBIM; hence they cannot determine the cost of implementation.

Considering the critical role played by BIM in achieving GreenBIM, it is not surprising to find it as a barrier to the actualisation of GreenBIM. The lack of BIM training, demand and skills must be overcome to achieve BIM. Kekana et al., (2014) and Olugboyega & Windapo, (2021) identified this as some of the challenges facing BIM adoption in the South African construction industry. Consequently, to achieve GreenBIM implementation, there is a need to achieve BIM diffusion.

5. Conclusion

The study identified the barriers to GreenBIM implementation in the south African construction industry through the perception of industry professionals. A quantitative approach was adopted through the random distribution of well-structured questionnaires to achieve this aim. Considering that Green BIM is a fusion of BIM, sustainability and green certification, it thus implies that achieving its implementation cannot be possible without achieving the components. It is thus not surprising from the results that professionals opined that there is a lack of GreenBIM guide in the south African construction industry. This is because the South African construction industry is still struggling with the adoption of BIM. Furthermore, the study result shows that there is a lack of government support, lack of incentives, and lack of BIM training, among others, to achieve GreenBIM. Thus there should be a conscious effort towards achieving GreenBIM by first addressing the barriers to BIM adoption and then creating awareness and clarity on the benefits of GreenBIM to the industry stakeholders. Also, the government must support and create incentives to motivate the adoption of GreenBIM, especially in the achievement of sustainable infrastructures. Overall, there must be a structure guiding the implementation of GreenBIM for a seamless implementation process.

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Machine learning-based recognition of mental fatigue in construction equipment operators using facial features.

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Abstract
Construction equipment operators are at risk of mental fatigue, which can lead to accidents and health problems. Real-time monitoring is necessary to prevent accidents and protect operators' well-being. Previous studies have used wearable sensors to classify mental fatigue in operators, but these methods require physical sensors to be worn, causing discomfort and irritation. Therefore, a new approach is needed that allows for contactless measurements of mental fatigue. In this study, a novel approach was proposed using machine learning and geometric measurement of facial features to classify mental fatigue states during equipment operations. Video recordings were obtained during a one-hour excavation operation, and four facial features (eye distance, eye aspect ratio, head motion, and mouth aspect ratio) were extracted for analysis. The temporal increase in NASA-TLX score was used as the ground truth for mental fatigue. The results showed that the support vector machine classifier outperformed, achieving a high accuracy of 91.10% and an F1 score between 85.29% and 95.61%. These findings suggest that mental fatigue in construction equipment operators can be non-invasively monitored using geometric measurements of facial features.

Keywords
Mental Fatigue, Machine Learning, Construction Safety, Facial Features, Construction Equipment Operators.

1. Introduction

Fatigue-related human behavior is a major cause of construction equipment accidents, accounting for over 65% of incidents (Bai and Qian, 2021). Construction tasks that demand sustained effort and attention lead to mental fatigue among equipment operators, impairing their judgment and focus (Das et al., 2020, Wagstaff and Sigstad Lie, 2011). This increases the likelihood of accidents, reducing productivity and performance (Masullo et al., 2020). To improve site safety, constant monitoring of equipment operators' mental fatigue is necessary (Han et al., 2019), allowing for swift action in response to signs of inattention.

Safety is paramount in construction work, and to ensure safety, mental fatigue of construction equipment operators needs to be assessed. Initially, mental fatigue was subjectively assessed through tools like NASA-TLX, which were intrusive and not suitable for continuous monitoring (Umer et al., 2020, Turner and Lingard, 2020). Technology advancements have made it possible to use physiological measurements like the electroencephalogram (Lee and Lee, 2022), electrodermal activity (Choi et al., 2019), eye tracking (Li et al., 2020), and the electrocardiograph (Umer et al., 2022) for an objective and real-time assessment of mental fatigue. However, these techniques have limitations, such as being invasive, sensitive to harsh conditions, requiring limited physical activity, and having poor spatial resolution (Kaur et al., 2022, Chen et al., 2015). Most studies such as by Liu et al. (2021) were conducted in simulated scenarios, limiting their applicability to construction sites. There is a need for non-invasive and contact-free detection of mental fatigue during ongoing equipment operations, and an automated early warning system will enhance safety at construction sites.

Despite the widespread use of facial feature recognition in other occupations, its application in the construction industry, particularly among excavator operators, remains a knowledge gap. As per the authors' knowledge, there are no existing studies that utilize geometric measurements of facial features to monitor the mental fatigue of construction equipment operators during operations. Furthermore, it is challenging to apply findings from other occupations, such as drivers, to detect mental fatigue during excavator operations due to the significant differences in working patterns.

Liu et al. (2021) found that construction equipment operators work differently than drivers, highlighting the need for a new approach for construction industry. Hence, this study proposes a novel approach of utilizing machine learning and geometric measurements of facial features to detect and classify mental fatigue states in construction equipment operators. By using a camera to take geometric measurements of the face regions, this non-invasive, efficient, and practical approach could enable real-time monitoring of excavator operators' mental fatigue. It is anticipated that this approach will improve mental fatigue detection during equipment operations, providing safety personnel with more effective and proactive responses.

2. Methodology

The proposed approach for detecting and classifying operator mental fatigue on construction sites using machine learning and geometric facial feature measurement is illustrated in Figure 1. The study was conducted on a construction site where a time-on-task experiment was performed to induce mental fatigue. The experiment involved operators performing a one-hour repetitive excavation and discharge task, which entailed excavating the ground and transporting excavated material from pits to vehicles. As this was a time-on-task experiment, the quantity of earth excavated or moved, and the number of vehicles filled were not predetermined. Furthermore, the operators did not undergo any practice sessions since they already had prior excavation operation experience. Five excavator operators participated in the research study, with a mean age of 31.25 years (SD = 2.39). All participants were experienced excavator operators, with an average of more than six years of experience in excavation operations at construction sites. They had slept for at least eight hours the previous night and had not consumed alcohol for at least 24 hours before the experiment. In addition, the temporal increase in NASA-TLX score was used to evaluate construction equipment operators' subjective feelings of mental fatigue and to establish their mental fatigue levels (alert state, mild fatigue state, and fatigue state). A color video camera placed 0.6m inside the equipment cabin was used to capture the operator's facial behavior. The camera was mounted on the windscreen to avoid visual obstruction and had a sampling frequency of 30 frames per second with a high resolution of 1440 x 1440 pixels.

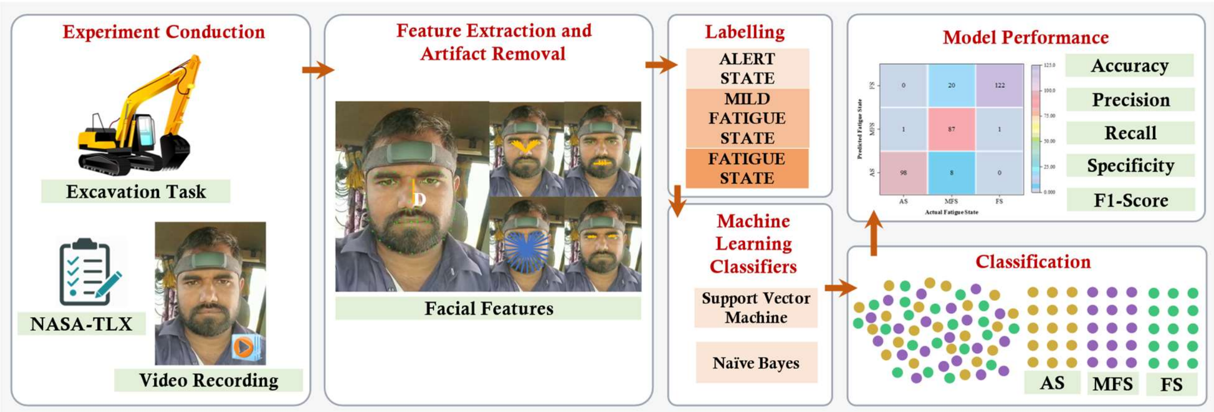

Figure 1: Framework of facial features based mental fatigue classification.

During excavation operations at the construction site, operators were recorded on video cameras for one hour. OpenCV, an open-source computer vision toolkit developed with Python, was used to convert the video footage of each operator into frames. Face recognition was then conducted on each frame using a local constrained neural field model (Baltrušaitis et al., 2016). The model was able to detect the operator's face in each frame, and the results were expressed as a vector $G = [a_1, a_2, a_3, \dots \dots \dots, a_i]^E$, representing 68 landmarks identified on the operator's face in each frame via Dlib (King, 2009). In this case, a represents a detected facial landmark at position (j_i, k_i) in any frame F, F is the number of any frame, and i is the index of detected landmarks at any frame, with values ranging from one to 68. Euclidean distance was calculated between any two desirable points, which was then used to compute the geometric measurements of four facial features investigated in this study (Mehmood et al., 2022). Four facial features were obtained individually from each frame and are outlined in Table 1 and presented in Figure 2. To eliminate artifacts in the facial feature data, nose landmarks represented by vector $D = [||a_{32} - a_{28}||]^E$ were used to create the nose line (Mehmood et al., 2022). This line's length was then employed to normalize all facial features by dividing them by D, resulting in normalized facial features for each frame.

To segment the facial feature data from the five operators, we utilized a sliding window approach with a window size segmentation of 20 seconds. Overlapping of consecutive windows was employed to ensure that no relevant data was missed, with a 50% overlap of adjacent data segment lengths in our study. As a result, a dataset of 1125 samples were generated for the five construction equipment operators. This dataset was divided into two parts, with 70% assigned for training and 30% designated for testing. To accurately classify mental fatigue using facial features data, we utilized two supervised machine learning classifiers: support vector machines (SVM) and naive bayes (NB). We evaluated the performance of the three machine learning models by using accuracy, precision, recall, specificity, and the F1-score. In addition, we plotted the confusion matrix to assess each model's performance in specific classes.

Table 1: Details of extracted facial features.

Facial Feature	Description and Computation
Eye Distance Sum (ED)	$ED = \|a_{31} - a_{43}\| + \|a_{31} - a_{44}\| + \|a_{31} - a_{45}\| + \|a_{31} - a_{46}\| + \|a_{31} - a_{47}\| + \|a_{31} - a_{48}\|$
Head Motion (HM)	$HM = \frac{1}{D}\sum_{i=1}^{E} \lvert a_{E1} - a_{E2}\rvert$
Eye Aspect Ratio (EA)	$EA = \frac{\|a_{44} - a_{48}\| + \|a_{45} - a_{47}\|}{2\|a_{43} - a_{46}\|}$
Mouth Aspect Ratio (MA)	$MA = \frac{\|a_{64} - a_{66}\| + \|a_{62} - a_{68}\| + \|a_{63} - a_{67}\|}{3\|a_{49} - a_{55}\|}$

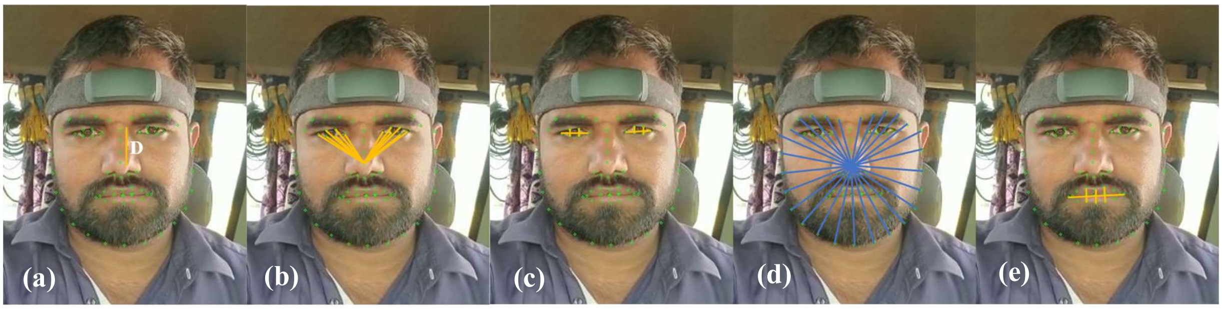

Figure 2: Extraction of facial features' geometric measurement (a) nose length (b) eye distance (c) eye aspect ratio (d) head motion (e) mouth aspect ratio

3. Results

3. 1 Ground Truth

In this study, the increase in NASA-TLX score over time served as an indicator of operators' mental fatigue. The results indicate that by the end of the experiment, participants' levels of subjective mental fatigue had increased from the baseline score of 10.20 (SD = 3.11) to a score of 61.60 (SD = 5.77), representing an increase that is statistically significant. Furthermore, the subjective scores for alert state, mild fatigue state, and fatigue state were 31.00 (SD = 2.65), 43.80 (SD = 2.95), and 61.60 (SD = 5.77), respectively. In addition, these subjective data indicate that as the excavation operation continued, the operators' mental fatigue increased.

3.2 Machine Learning-based classification results

Table 2 and Figure 3(a) display the SVM model's evaluation metrics and confusion matrix, respectively. The evaluation metrics show that the SVM model performed well in identifying various levels of mental fatigue in construction equipment operators using facial features data. The SVM model achieved precision values ranging from 85.92% to 97.75%, with MFS being accurately identified in 97.75% of cases. The SVM model was less affected by AS and FS than by MFS. Additionally, the model had higher recall and precision values, indicating fewer false negatives and false positives, respectively. The specificity and F1-score measures ranged from 90.65% to 99.10% and 85.29% to 95.61%, respectively. A high specificity implies a high true negative rate, indicating that a person identified as fatigued was indeed in that state. The confusion matrix, as shown in Figure 3(a), determined whether classes were misclassified or confused with others. Correctly classified cases were represented by diagonal members of the matrix, while incorrectly classified instances were represented by nondiagonal elements. FS was more often misclassified than AS and MFS, but the misclassification rate for AS and FS was modest. Additionally, FS was confused with MFS in 20 instances.

The evaluation metrics and confusion matrix for the naive Bayes (NB) model are presented in Table 2 and Figure 3(b). The diagonal cells in the matrix provide the correct classes, allowing for a more thorough evaluation of classification performance. However, when compared to the SVM classifier, the NB classifier's evaluation metrics showed the lowest performance. Precision values for the NB model ranged from 69.77% to 84.91%, with AS achieving the highest percentage of accurately classified instances at 90.91%, while MFS had the lowest accurately categorized instances at 67.83%. Additionally, AS was confused with MFS 30 times, and MFS was confused with FS 24 times. Specificity measurements ranged from 83.61% to 92.52%, and the F1-score ranged from 71.89% to 78.94%. These findings suggest that the NB classifier was not as effective as the SVM classifier in classifying mental fatigue in construction equipment operators based on facial feature data.

Table 2: Performance assessment metrics for machine learning classifiers

Support Vector Machines (SVM) Classifier					Naïve Bayes (NB) Classifier				
Indicator	**Testing**	**AS**	**MFS**	**FS**	**Indicator**	**Testing**	**AS**	**MFS**	**FS**
Accuracy	91.10%				Accuracy	76.60%			
Precision		92.45%	97.75%	85.92%	Precision		69.77%	76.47%	84.91%
Recall		98.99%	75.65%	99.18%	Recall		90.91%	67.83%	73.17%
Specificity		96.64%	99.10%	90.65%	Specificity		83.615	89.19%	92.52%
F1-score		95.61%	85.29%	92.06%	F1-score		78.95%	71.89%	78.60%

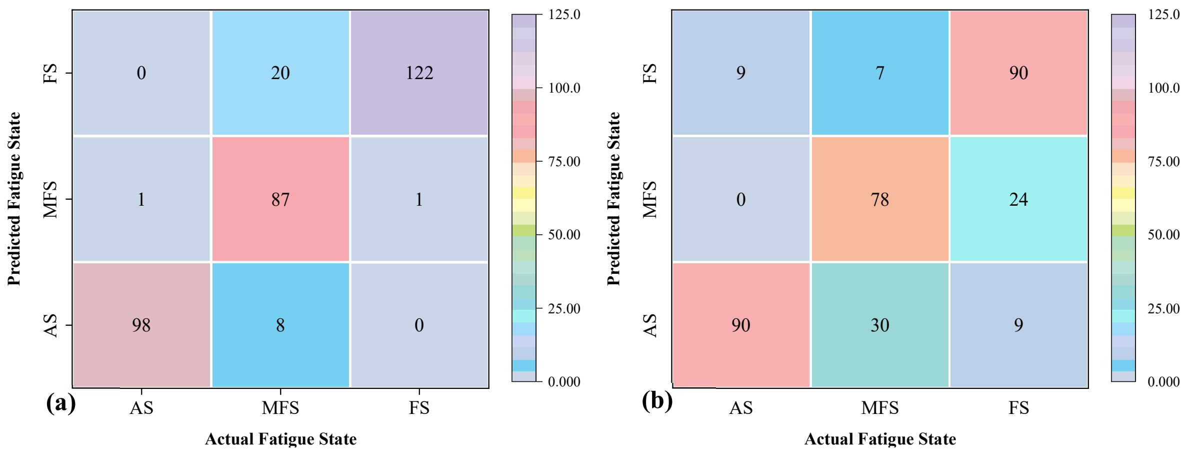

Figure 3: Confusion matrix (a) support vector machine (b) naïve bayes

4. Discussion

Construction equipment operators must remain alert and focused for extended periods, which can lead to mental fatigue and increase the risk of accidents on construction sites. This study proposes a machine learning-based approach that uses geometric measurements of facial features to recognize and classify different types of mental fatigue states during equipment operation. Four facial features were gathered during on-site operations, and the performance of two machine learning classifiers, support vector machines (SVM) and naïve bayes (NB), were compared. This study is the first to propose a machine learning-based approach for recognizing and classifying mental fatigue states in construction equipment operators using contactless measurements from video cameras. The results show that mental fatigue can be accurately classified in construction equipment operators with varying levels of mental fatigue using this approach.

Our study compared the performance of two machine learning classifiers, and we found that the SVM classifier outperformed the NB classifier. Using facial features as input data, the SVM classifier achieved an overall accuracy of 91.10%, with precision, recall, specificity, and F1-score values ranging from 85.92% to 97.45%, 75.65% to 99.18%, 90.65% to 99.10%, and 85.29% to 95.61%, respectively. Additionally, the SVM classifier had a lower misclassification rate for the three mental fatigue states than the NB classifier. These findings suggest that geometric measurement of facial features is an effective approach for identifying and classifying mental fatigue in equipment operators.

Our study's approach, which utilized machine learning and facial features data, achieved higher classification accuracy compared to previous studies in the construction domain that only used wearable sensors as input data. For instance, Jeon and Cai (2022) used a two-step ensemble approach with single-modal EEG data to classify hazard recognition and cognitive states and achieved 82.3% accuracy with the LightGBM classifier. Similarly, Jebelli et al. (2018) employed non-linear support vector machines to classify construction worker stress with 71.1% accuracy using EEG data on a construction site. Additionally, Jebelli et al. (2019) used deep learning neural networks to classify mental stress with 86.62% accuracy. However, comparing our results directly with these studies can be challenging due to differences in experimental setups, task nature, number of subjects, and individual differences.

5. Conclusions

This study presents a novel approach to classifying mental fatigue in construction equipment operators using supervised machine learning and geometric measurements of facial features. The experiment involved five equipment operators who performed an excavation task on a construction site, with the temporal increase in the NASA-TLX score serving as the ground truth for assessing mental fatigue. Facial features of the operators were recorded through video to measure their geometric changes during the task. The monotonous and prolonged nature of the excavation task induced mental fatigue, and four distinct facial features were extracted and labeled into three mental fatigue states: alert state, mild fatigue state, and fatigue state. Two supervised machine learning classifiers, SVM and NB, were utilized to classify the three mental fatigue levels. Evaluation metrics such as accuracy, precision, recall, specificity, and F1-score were used to measure the performance of the models. The results indicated that the SVM classifier outperformed the NB classifier, achieving an overall accuracy of 91.10%. The findings suggest that the SVM classifier can effectively classify mental fatigue states during construction equipment operations, enabling the development of a real-time system of video cameras and machine learning to classify mental fatigue in operators, to enhance safety and health management on construction sites.

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Impact of emerging digital technologies on offsite construction: insights from literature

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Abstract
The implementation of emerging digital technologies such as 3D printing and blockchains into offsite or modular construction can facilitate the wider acceptance of this modern method of construction. This study aims to analyse the impact of emerging digital technologies on offsite construction. A literature review was conducted in this research to reveal the benefits of emerging technologies. The digital technologies examined in this study having innovative impact on offsite construction are 3D Printing, Internet of Things, Extended Reality, Artificial Intelligence, Robotics, Blockchain, Laser Scanners and Photogrammetry, and Digital Twins. Adopting digital technologies in offsite construction can improve design and planning, increase efficiency and productivity, enhance quality and safety, and increase sustainability.

Keywords
Offsite construction, Digital technologies, Review of literature, Modular construction, Industry 4.0

1. Introduction

Offsite construction, also known as prefabricated construction, panelised construction or modular construction refers to the completion of building components in a factory before they are moved to a different location where they will be installed in their final location (Staib et al., 2017) (Christopher Rausch et al., 2019) (Altaf et al., 2018) (Zoloedova et al., 2017). This method of construction has increased in popularity in the last two decades, however offsite construction adoption is still hindered due to several issues such as inflexibility in design change, long design times, lack of quality inspection and low supply change efficiency (W. Zhang et al., 2018).

The adoption of emerging digital technologies has proven its benefits in several industries including manufacturing (M. Yang et al., 2021) (Blichfeldt & Faullant, 2021)(Rodríguez-Espíndola et al., 2022) and construction (Mannino et al., 2021).

The combined outcomes of those digital transformation that trigger new developments in industries is part of the industry 4.0 or fourth industrial revolution. The main technology enablers include the Internet of Things (IoT), artificial intelligence, and visualisation (Szalavetz, 2019). The use of these technologies paired with Building Information Modelling (BIM) has become fundamental to the enhancement of a collaborative and efficient planning and design of construction projects including offsite construction (D Lee et al., 2021).

There is a growing interest in the adoption of digital technologies in offsite and prefabricated construction explaining the theories and their applications (Cheng et al., 2023). In general, the existing research have proven that digital technologies can improve efficiency of offsite construction (M. Wang et al., 2022) (M. Wang et al., 2020). The aim of this research is to analyse the impact of emerging digital technologies on offsite construction. This will be achieved by identifying the key digital technologies that are currently used in offsite modern methods of construction. The study will then focus on the benefits of integrating technologies that have been displayed in the literature.

2. Methodology

A brief literature review is conducted in this study to examine the impact of emerging digital technologies on offsite construction. The keywords used for data collection include “Digital technologies” AND “off-site construction” OR “modular construction” OR “prefabrication construction” OR “modular integrated construction” OR “modular buildings” OR “prefabricated building” OR “offsite construction” OR “volumetric construction.” OR “panelized construction”. The keywords were used to generate search strings to discover relevant papers. The resulting articles were filtered by only including “journal” and “conference” papers to ensure the quality of the study. Further manual screening was performed by reading the title and abstract to remove unrelated articles. Out of the plethora of papers found, only 41 were selected for this research as displayed in table 1 with the corresponding digital technology. The key digital technologies influencing offsite construction were identified by thoroughly studying the results of the literature screening. Furthermore, a survey was conducted among construction professionals experienced in modern methods of construction. The questionnaire was sent to nearly 190 participants using LinkedIn messaging and emails and 14 responses were received. Although the response rate is low compared to other industrial surveys, however, there is a noticeable decline in responses in recent years particularly for online surveys compared to paper based counterparts (M. J. Wu et al., 2022). This will be taken into consideration for forthcoming research. Figure 1 displays a word cloud of the digital technologies that the participants foresee being used in the near future. It can be observed BIM got the highest number of votes reflected by the larger font size followed closely by Unmanned Aerial Vehicles (UAVs) or drones. Real-time data, robotics and artificial intelligence are among those mentioned.

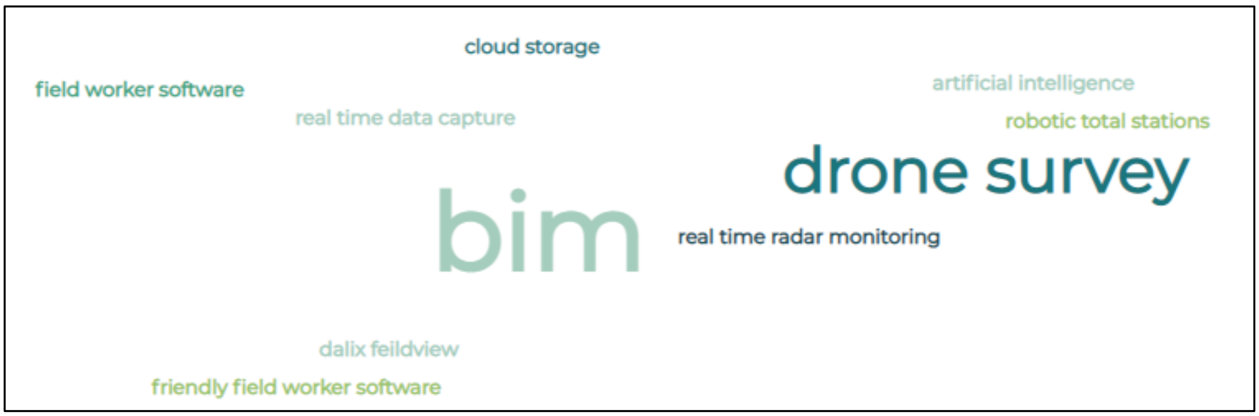

Figure 1- Digital technologies participants forecast to be used in the near future

3. Results

The success of offsite construction methods depend immensely on adopting digital technologies, however a study conducted in 2020 found that only 12.8% of the overall research published around offsite construction involves digital technologies (M. Wang et al., 2020). Moreover, the survey conducted as part of the current study reveals that only 28% of the respondents have heard of the term “industry 4.0”. This indicates that the concepts used in academia are not being addressed as part of the continued professional development in the industry.

Several technologies are greatly aiding the development of offsite construction underpinned by BIM processes, from extended reality to 3D printing. Presented below are the potential benefits and likely influences of using these technologies in offsite construction. Table 1 displays a summary of the likely outcomes of those technologies.

3D Printing

3D printing is one of the most essential tools of industry 4.0 (Jandyal et al., 2022). It supports sustainability as it saves time and cost compared to traditional methods of construction (Han et al., 2020) as well as noticeably lowering labour cost (Y. He et al., 2020; H. Yang et al., 2018). It is evident from the literature that 3D printing reduces the cost of formwork as 3D concrete printing does not use supporting formwork (Paul et al., 2018) especially for geometrically uneven buildings (Y. He et al., 2020).

Internet of Things (IoT)

Internet of Things (IoT) is a powerful paradigm that has been widely adopted in off-site construction (L. Wu et al., 2022)(Razkenari et al., 2020). IoT sensors and devices can provide the ability for real-time monitoring of the construction site and equipment (Gbadamosi et al., 2019)(Aisyah Jaafar et al., 2021), which enables detecting process abnormalities in turn optimising the construction implementation process (Yuan et al., 2021). Real- time data can also be used to track the movement of materials and equipment throughout the supply chain (Kazmi & Sodangi, 2022)(Hussein et al., 2021). This helps predict potential logistic risks enabling effective supply chain coordination (Dongmin Lee & Lee, 2021). Moreover, IoT sensors have been used for quality control purposes of prefabricated buildings through offsite construction (Yao et al., 2021). The integration of this real-time data with Building Information Models can help improve the efficiency, accuracy (G. Xu et al., 2018)(C. Z. Li et al., 2016) and safety (Teizer et al., 2017) of offsite construction.

Extended reality

Extended reality (XR) includes several immersive technologies that transform reality by adding virtual experiences to the real-world environment. It includes virtual reality (VR), augmented reality (AR) and mixed reality (MR) (Alizadehsalehi et al., 2020). AR technology can be combined with BIM models and data to optimise the design and planning processes allowing architects and other project stakeholders to share viewings. It can also be used for the confirmation of construction management information through visualisation during the construction phase (Chung et al., 2021). AR also helps reduce on-site error and possibilities of rework (Gimeno et al., 2018), as well as aiding inspection of prefabricated buildings (García-Pereira et al., 2020). MR method is also used for off-site construction supervision with the aid of BIM data and drone videos (Raimbaud et al., 2019).VR tools play in role in enhancing safety as well through visualising crane lifting paths to avoid any collisions that might occur (Z. Zhang & Pan, 2019).

Artificial Intelligence

AI implies using machines to model intelligent behaviour such as reasoning, learning and knowledge with minimal human intervention (Mohammadpour et al., 2019). It is a broad field that includes Machine Learning (ML) and Deep Learning (DL). These technologies helps industry practitioners in offsite manufacturing to make better decisions (Hwang et al., 2018), whether it be quality control during the assembly process (Arashpour et al., 2019), assisting decision makers to improve project planning and control through cost-time adjustments (Hamdan et al., 2016) or enabling better estimation of transportation costs for panelised construction projects (Ahn et al., 2020). Similarly AI combined with BIM technology can be used to automate designs resulting in time saving for the offsite process (H. Liu et al., 2018). ML techniques have been used in aiding in Offsite assembly (Tuvayanond & Prasittisopin, 2023) (Abioye et al., 2021). In terms of safety of construction workers AI technology has been researched in monitoring crane operators physical conditions and alerting them in signs of fatigue during the prefabricated assembly process (X. Li et al., 2019).

Robotics

Robotics have been increasingly used in recent years within the manufacturing industry. This has prompted construction practitioners to explore robotics potential in both onsite and offsite construction (M. Tehrani et al., 2022). Robotics have proven to increase production rates while reducing overall cost (Tehrani et al., 2022). Researchers have also explored the use of robots in construction waste sorting (Chen et al., 2022). BIM authoring tools have been utilised to aid robots in performing designated tasks that need explicit information, this approach has the potential of reducing errors from design to build in the construction industry (Wong Chong et al., 2022). Similarly, BIM is used within offsite construction systems for Construction automation purposes. Allowing the development of a design to manufacturing framework (Anane et al., 2023).

Blockchain

Blockchain technology can be used in offsite construction for supply chain management (Xiao Li et al., 2021) and for improving traceability (Z. Wang et al., 2020). It is combined with IoT systems to ensure construction material origin through tracking and tracing to avoid false material (J. Xu et al., 2023). Blockchain is also integrated within digital twins specifically to oversee fit-out operations in modular integrated construction (Jiang et al., 2023). However, this is still a work in progress and has not proven efficiencies in cost reduction.

Laser Scanners and Photogrammetry

Laser scanners have gained popularity in recent years as measuring tools in the construction industry (Bassier et al., 2016). Those methods of 3D scanning are used to model the terrain of the construction site directly developing 3D point clouds at high levels of accuracy (C Rausch et al., 2021). Both laser scanning and photogrammetry can be utilised for that purpose (Zhen Liu & Deng, 2017). Those methods have been progressing in recent years integrating them within other digital technologies such as UAVs and BIM (Murtiyoso & Grussenmeyer, 2018). The integration of 3D laser scanning and BIM has displayed potential for modular construction quality control.

Digital Twins

Digital twin concept is used to optimise buildings performance throughout their lifecycle. This can be applied within prefabricated buildings to assist with data-driven decision making. Data can be collected from prefabrication procedures through IoT sensors, and then predictive analysis can be performed, optimising the control decisions for manufacturing facilities operations (R. He et al., 2021), or as an effective security management and decision making tool (Zhansheng Liu et al., 2021).

Table 1. Benefits of digital technologies in offsite construction

Digital Technology	Likely Outcomes	Relevant Literature
3D Printing	- Cost saving by decreasing cost of labour significantly - Time saving as it supports mass production - Improves accuracy by eliminating human error	(Paul et al., 2018) (Han et al., 2020) (Y. He et al., 2020) (H. Yang et al., 2018)
Internet of Things	- Monitoring of construction site and equipment - Supply chain management - Quality control - Safety by providing alerts for potential hazards	(Gbadamosi et al., 2019)(Aisyah Jaafar et al., 2021) (Yuan et al., 2021). (Kazmi & Sodangi, 2022)(Hussein et al., 2021) (Dongmin Lee & Lee, 2021).
Extended Reality	- Optimise design and planning processes - Confirmation of construction management information - Reduce on-site errors and possibilities of rework - Aiding inspection of prefabricated buildings - Off-site construction supervision - Enhancing safety through visualisation	(Yao et al., 2021) (Teizer et al., 2017) (Chung et al., 2021) (Gimeno et al., 2018) (García-Pereira et al., 2020) (Raimbaud et al., 2019) (Z. Zhang & Pan, 2019)
Artificial Intelligence	- Quality control - Improve project planning and control - Estimation of transportation costs for panelised construction projects - Enhance and automate the design practice - Optimise structural performance - Aiding Offsite assembly - Safety of construction workers	(Hwang et al., 2018)(Arashpour et al., 2019)(Hamdan et al., 2016) (Ahn et al., 2020) (Abioye et al., 2021) (H. Liu et al., 2018) (Baghdadi et al., 2020) (Tuvayanond & Prasittisopin, 2023) (Abioye et al., 2021)(X. Li et al., 2019)
Robotics	- Increase production rates - Reduce overall cost - Construction waste sorting - Reduce errors from design to build - Construction automation	(Tehrani et al., 2022) (Chen et al., 2022) (Wong Chong et al., 2022)
Blockchain	- Supply chain management - Improving traceability - Oversee fit-out operations - Project supervision	(Xiao Li et al., 2021) (Z. Wang et al., 2020) (J. Xu et al., 2023) (Jiang et al., 2023) (R. Yang et al., 2020)

Laser Scanners and Photogrammetry	- Quality control - Improve dimensional quality - Geometric quality inspection - Improving safety	(H. Li et al., 2020)(Christopher Rausch et al., 2020) (Guo et al., 2020) (Goh et al., 2019) (Gilmour & Stroulia, 2022)
Digital Twins	- Assist with data-driven decision making - Effective security management	(R. He et al., 2021) (Zhansheng Liu et al., 2021)

4. Discussion

This research aimed to analyse the impact of emerging industry 4.0 enabling technologies that are most commonly used in offsite construction. This was achieved by first highlighting the emerging technologies and respectively displaying their benefits as can be seen in figure 2. The use of digital technologies has proven improvements in many aspects of offsite construction. For example, compared to conventional methods of construction, 3D printing technology enables cost and time reduction (Han et al., 2020) as well as significantly reducing labour costs (Y. He et al., 2020; H. Yang et al., 2018). It is also clear from the above results that 3D printing reduces the cost of formwork as 3D concrete printing does not use supporting formwork (Paul et al., 2018) especially for geometrically uneven buildings (Y. He et al., 2020).

Another aspect that displays potential is the increased efficiency of supply chain coordination and management. IoT can track the movement of materials and equipment (Kazmi & Sodangi, 2022)(Hussein et al., 2021), this helps predict potential logistic risks enabling effective supply chain coordination (Dongmin Lee & Lee, 2021). Combined with blockchain technology it can improve traceability (Xiao Li et al., 2021) (Z. Wang et al., 2020). In terms of safety, it can increase considerably by the use of real-time data integrated in BIM models (Teizer et al., 2017), as well as enhancing the safety of crane lift operations through VR, AI and laser scanning technologies (Z. Zhang & Pan, 2019)(X. Li et al., 2019)(Goh et al., 2019).

Adoption of smart technologies such as IoT sensors, AI and 3D laser scanning enables better methods of quality control of offsite projects, whether it is during the project planning or assembly process (Yao et al., 2021)(Arashpour et al., 2019). Furthermore, those technologies can improve the accuracy of conducting offsite projects through the integration of real-time data with BIM (G. Xu et al., 2018), moreover 3D scanning is used to model the terrain of the construction site directly developing 3D point clouds at high levels of accuracy (C Rausch et al., 2021) compared to traditional methods of surveying. Robotics and the use of BIM authoring tools can aid in performing designated tasks that need explicit information, and the approach has potential of reducing errors from design to construction.

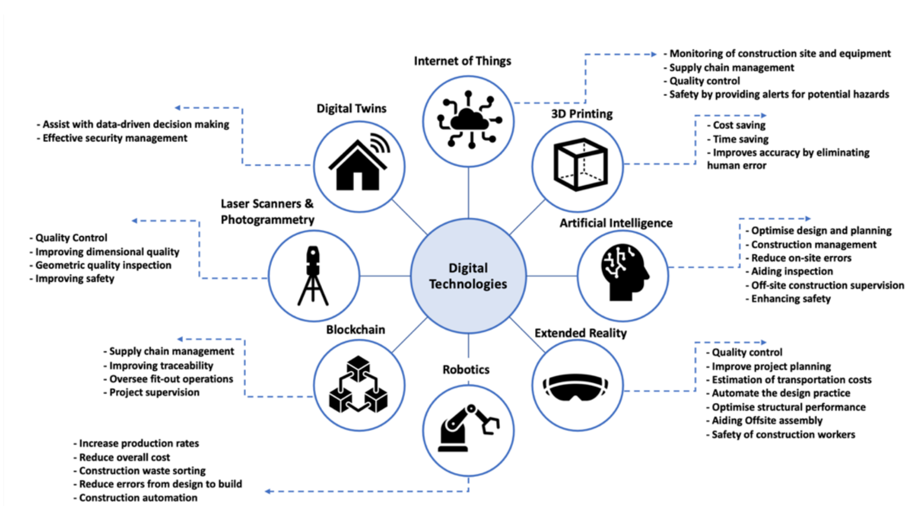

Figure 2- Applications of digital technologies in offsite construction

5. Conclusions

The purpose of this present study is to investigate the impacts of digital technologies on offsite construction. A succinct literature review is carried out along with an online survey of industry professionals. The identified technologies include 3D Printing, IoT, XR, AI, Robotics, Blockchain, Laser Scanners and Photogrammetry, and Digital Twins. The investigation revealed significant impact of emerging digital technologies on offsite construction in key areas such as:

1- Improved design and planning: For example, through artificial intelligence and extended reality.

2- Increased efficiency and productivity: For instance, robotics and automation systems have the ability to perform repetitive tasks. 3D printing plays a role in improving accuracy and eliminating human errors.

3- Enhanced quality and safety: the use of sensors powered by IoT systems enables monitoring of conditions of equipment and material of construction sites. Extended reality can also be used to train workers and aid them in offsite assembly, helping them to detect potential hazards consequently improving the overall safety awareness.

4- Increased sustainability: 3D printing can be used to create components with minimal waste, as well as saving cost and time. Robotics and automation can also reduce the environmental footprint by reducing errors from design to build and reducing overall cost.

This review raises theoretical and practical implications, it serves as a guide for future researchers to understand the current state of impact of digital technologies on offsite construction. It also contributes for industry professionals as it offers information on technologies that can be employed in the process of digitization of offsite construction.

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Modelling the impact of technological innovations on the sustainability of South African affordable housing projects

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Abstract
Sustainable, affordable house development can be facilitated by adopting appropriate technological innovations. However, limited studies provide practical knowledge on the impact of key influencers on adopting these technological innovations in African affordable housing projects. Therefore, the impact of internal and external influencers on the degree of technological innovation adaptation in South African affordable housing projects is examined in the current study. The initial findings were used to develop a sustainable, innovative, affordable housing (SIAH) causal model. The developed casual model and the relationship between the constructs/sub-constructs were validated through structured data collected from official South African home developers. The study found a low positive impact of internal influences and a moderate negative impact of external influences on home developers' adoption of technological innovation in South African affordable housing projects. Moreover, the research proved the high negative mediating impact of external influences on the association between internal influences and technological innovation adoption level. The study deduces that external influencers are the main drivers of adopting technological innovation in affordable housing, which means that by addressing the external influences, the level of adoption will significantly improve. This is due to the direct and mediating adverse effects of external influencers on adopting technological innovation in affordable housing projects. The SIAH model can be a robust framework to reduce the challenges of adaptation to technological innovations in SIAH.

Keywords
Affordable housing, Internal and external influences, Level of adoption, Sustainability, Technological innovation.

1. Introduction
Sustainability and innovation are positive changes in the construction industry, particularly the housing sector, due to alternative construction methods, sustainable materials, and new technologies (Moghayedi et al., 2021). Although a perception exists that innovation in construction projects, particularly affordable housing projects, is limited, improving productivity and quality, reducing cost and time of projects, and consequently, the sustainability of the project and meeting or exceeding projected goals often require innovation (Adabre et al., 2021). Sustainability practices and innovation within affordable housing projects provide the opportunity to not only reduce the cost and improve the quality of the housing but also enhance the environmental and social aspects of houses and therefore assist in developing sustainable, affordable housing, which is a competitive market, is a requirement for continued existence (Jamaludin et al., 2018). According to Moghayedi et al., (2022), a series of related events must occur in order for a sustainability practice or innovation to be successfully implemented; mere awareness of it does not guarantee adoption. Therefore, it is necessary to determine the critical internal factors influencing the adoption of sustainability and innovation in housing projects at both the project and company levels and external influencers. However, knowing which company and project factors are truly supportive requires a deep understanding of the process home designers and developers undertake in deciding to use sustainable methods and materials and new technologies in designing and constructing affordable housing projects. Knowing why, where and how home designers and developers adopt technological innovations and sustainability is crucial because it can expedite the diffusion rate of SIAH by facilitating their adoption. Therefore, it is necessary to research the internal and external factors that affect how technological innovations are adapted in affordable housing projects to provide a systematic overview to support

housing sectors and industry players in streamlining the process and, ideally, become more successful at utilizing the most appropriate alternative methods, sustainable materials, and new technologies to enhance the sustainability of affordable housing.

However, the role of technological innovations and their impacts on the sustainability of construction projects, particularly affordable housing, needs to be better understood. There is a clear need to rectify this. Moreover, current studies did not provide extensive quantitative analysis and understanding of the impact of critical internal and external influence factors on the level of adaptation of alternative methods, sustainable materials and new technologies in affordable housing projects in the global south. Several scholars emphasized this exciting gap and recommended a deep understanding of the impact of the key influential factors on sustainability and innovation in affordable housing projects (Moghayedi et al., 2021). Thus, this study aims to provide a deep understanding of the role of these influential factors in affordable housing projects by determining the nexus between the key internal and external drivers and level of adoption of technological innovations in affordable housing projects and how these factors and challenges impact on the level of adoption of sustainability and innovation in affordable housing projects.

2. Literature Review

The sustainable housing concept lacks urgency in the affordable housing sector. Most designers and developers do not demand it due to a lack of knowledge, which is not regulated by law (Adabre et al., 2021). The action for the SIAH concept is business-driven for some large developers. For many developers, profits are generated using conventional construction methods and materials to minimize the construction cost of housing regardless of the adverse effects it may cause on houses, which still dominate the sector (Moghayedi et al., 2022). Without considering the operating cost of developers in the housing industry, most developers tend to ignore the need for sustainability and innovation in the design and construction of affordable houses (Patel & Padhya, 2021). Adopting technological innovation in affordable housing creates an opportunity to enhance the sustainability of affordable housing (Moghayedi et al., 2021). Technological innovation is a robust source of innovation that can provide construction companies with new technologies that can adequately complement and transform existing technologies to create and sustain better performance. There are many types of innovations, and each one may apply to the building and particularly affordable housing sector. To significantly reduce the negative environmental impacts of buildings and improve the social and economic aspects, the adoption of sustainable design methods, alternative construction methods, natural materials and new technologies in the design, construction and operation of affordable houses are necessary (Moghayedi et al., 2021). Sustainability and innovation such as passive design, net-zero buildings, off-site construction, lean construction, renewable energy, water reuse, recycled materials and many more technological innovations have already been introduced to the construction industry. But the number of technological innovations used in affordable housing is still limited, and the sector significantly faces some challenges in adopting technological innovation (Jamaludin et al., 2018). According to Moghayedi et al. (2022), the level of adoption of technological innovations is a function of readiness and awareness for the innovation and enablers and barriers in adopting that technology.

Internal influencers refer to companies' and projects' characteristics that can encourage the adoption of technological innovations in housing projects. It can be divided into interest and commitment, policies and management, and resources and capability. Patel & Padhya, (2021) defined the influential internal factors as competency, commitment, and actions within construction organizations to adopt appropriate technological innovations to pursue sustainable projects. How sustainability and innovation are adopted in construction projects and what barriers and challenges impede sustainability and innovation processes are heavily related to the construction organizations' characteristics and project attributes (Banihashemi et al., 2017). Moghayedi et al. (2022) proved that knowledge about sustainability and technological innovations within construction companies enable the adoption of proper alternative methods, sustainable materials and new technologies in the projects. Moreover, advancing the adoption of sustainability and technological link to the climate and structure of a construction company and project (Banihashemi et al., 2017). Moghayedi et al. (2022) acknowledged the organizational characteristics such as the size of the company, establishment, expertise in a particular type of project, awareness and familiarity of company management and staff with sustainability and technological innovations as being essential to the level of adoption of technological innovation and sustainability in the construction projects. On the other hand, at the project level, Ozorhon and Oral (2017) determined that project attributes such as the project size, project type, project procurement and client of the project influence the adoption of technological innovation and sustainability in the construction projects. Moreover, contracting methods and procurement that legally and contractually form the project design and construction and encourage phase overlap contribute significantly to construction project sustainability and innovation (Naoum & Egbu, 2016).

Moreover, the awareness and familiarity of designers and home developers with relevant technological innovations and sustainability and innovation is an important factor in affecting the degree of success in the process and results of sustainability and innovation in affordable housing projects (Adabre & Chan, 2020). Banihashemi et al. (2017) argued that project clients serve a vital role in construction projects' sustainable and innovative capacity. Akmam Syed Zakaria et al. (2018) stated that the size and type of project are major factors that affect the interest of many home designers and developers in sustainable, affordable projects by adopting more innovative methods, materials and technologies in the project. The sizes of the company also affect the capability to execute more innovative and sustainable practices in housing projects. Large construction firms can adopt more advanced and sustainable technological innovations because of their wide-range experience and skills, expertise, substantial capital, total commitment from leadership, and target projects and clients. Instead, small construction firms tend to keep costs to the minimum and adopting more technological innovations would invariably affect their profit margin (Akmam Syed Zakaria et al., 2018).

On the other hand, there are several barriers and challenges to adopting technological innovations as a sustainability catalyst in affordable housing projects in the global south, which are considered influential external factors. However, these challenges to innovation and sustainability exist at the project, company, and industry levels (Adabre et al., 2021). Policy and administrative barriers such as lack of regulation and policy and lack of incentive at the design and construction phases negatively affect the adaptation of technological innovations in housing projects (Kornilov et al., 2020). According to Moghayedi et al. (2022), limited home developers have the capability and interest to go beyond the lack of public or private incentives. Technological innovations pose a significant challenge for the construction industry, particularly the housing sector, due to the high cost of implementation, the difficulty of obtaining local technological innovations and sustainable materials and the lack of local technical skills to operate them (Patel & Padhya, 2021). Furthermore, Patel and Padhya (2021) identified the fear of upfront cost as the main reason for ignoring the implementation of technological innovations in affordable housing projects. Using alternative methods, sustainable materials, and new technologies requires new knowledge and skill. Therefore, a lack of technical knowledge and skills is a barrier to adopting technological innovations and, consequently, a failure to deliver sustainable buildings (Adabre & Chan, 2020). Since the technical knowledge and expertise of SME home developers in developing countries on technological innovations and sustainability are still low, they tend to appoint external experts, which adds to the overhead cost of projects (Pablo & London, 2020). Moghayedi et al. (2022) argued a need for local technological innovations in developing countries. As a result, it can be challenging to obtain alternative methods, sustainable materials and new technologies from the local market. The innovative building materials are mainly imported, leading to materials costs. Based on the abovementioned literature review, it is clear that project and company characteristics attributed as internal variables and challenges as external variables influence the adoption of technological innovations and sustainability in the affordable housing projects in the global south.

3. Research Design and Methodology

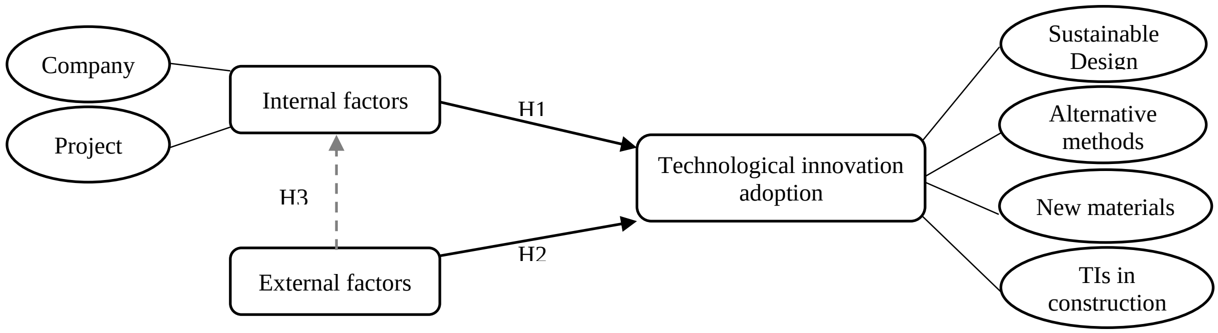
The study adopted a quantitative research design under a positivism philosophical approach to employ empirical methods, and makes extensive use of quantitative analysis to build a casual model for evaluating the effects of the project and company characteristics as internal influential and challenges as external influential variables on the level of adoption of sustainable design methods, alternative constriction methods, sustainable materials and new technologies by housing developers in the housing projects in South Africa. Based on the literature review, a causal model for adopting technological innovations in affordable housing was developed, as shown in Figure 1.

Based on the research objectives and developed casual model, the research is designed to test the following hypotheses:

- H1: Project and company characteristics as influential internal factors have a significant positive impact on the level of adoption of technological innovation in affordable housing projects
- H2: External influential factors have a significant negative impact on the level of adoption of technological innovation in affordable housing projects
- H3: External influential factors are negatively mediating the impact of influential internal factors on the level of adoption of technological innovation in affordable housing projects

A structured questionnaire survey was designed to gather the necessary data, and it was circulated using SurveyMonkey among the registered low-cost housing developers in South Africa. There were 517 valid responses collected across South Africa and used for data analysis. The questionnaire consisted of three following sections: 1. general information about home developer companies, 2. information on the level of adoption of technological innovations in previous affordable housing projects and 3. effect of internal and external influential factors on the level of adoption of sustainability and technological innovations in previous affordable housing projects using Likert scale. The collected data were analyzed using descriptive and inferential statistical techniques to develop the company profiles and level of adoption of technological innovations. Finally, the developed casual model was validated using structural equation modelling (SEM) and the impact of influential factors on the adoption of technological innovations in affordable housing projects was quantified.

Fig. 1. Causal model of sustainable, innovative, affordable housing (SIAH)



3. 1 Research constructs and sub-constructs

The internal and external influential constructs and their sub-constructs and variables are listed in Table 1. Based on the literature review, the authors identified eight internal factors (company: 4, project: 4), ten variables for influential external factors, and 14, 9, 6 and 17 innovations for sustainable design, alternative methods, sustainable materials, and new technologies respectively as summarized in Table 1.

Table 1. Variables used in measuring the study constructs

Constructs	Sub Constructs	Variables	Source
Internal (I)	Company characteristics (C)	Company size (IC1), Relevant experience (IC2), Company establishment (IC3), Awareness and familiarity with sustainability and innovation (IC4)	1, 2, 3, 4, 5, 6
	Project characteristics (P)	Project size (IP1), Housing type (IP2), Project client (IP3), Project procurement (IP4)	1, 2, 3, 4, 5
External (E)		High cost (lifecycle) (E1), Lack of technical standards (E2), Incompatibility with other methods, materials or technologies (E3), Tendency to use conventional methods, materials and technologies (E4), Lack of public incentives (E5), Lack of technical skill and knowledge (E6), Lack of awareness of the availability (E7), Lack of policy and regulation (E8). Low social acceptance (E9). Low availability in the local market (E10)	6, 7, 8, 9
Innovations (I)	Sustainable design methods (D)	Passive design (ID1), Inclusive design (ID2), Cultural and heritage conservation design (ID3), Disaster resistance (ID4), Green building (ID5), Natural lighting (ID6), Natural ventilation (ID7), Passive thermal (ID8), Life-cycle cost (ID9), Life-cycle energy (ID10), Life-cycle carbon footprint (ID11), Water conservation (ID12), Renewable energy (ID13), Lean design (ID14)	6, 8, 9
	Alternative construction methods (A)	Water-efficient methods (IA1), Energy-efficient methods (IA2), Deconstruction/disassembly methods (IA3), Prefabrication (IA4), Modular (IA5), Construction waste management (IA6), Lean construction (IA7), Safe methods (IA8), Less labour intensive (IA9)	6, 7, 8, 9
	New building materials (M)	Natural materials (IM1), Local materials (IM2), Recycled materials (IM3), Green materials (IM4), Light materials (IM5), Nanomaterials (IM6)	6, 8, 9
	New technologies (T)	Computer-Aided Design (CAD) (IT1), Object-oriented Computer-aided design (IT2), Engineering design software (IT3), Artificial intelligence in design (IT4), Building Information modelling (IT5), Virtual Reality (IT6) Augmented Reality (IT7), Mixed Reality (IT8), Project portfolio management software (IT9), Laser scanner (IT10), Geographic Information System (IT11), Drone (IT12), Sensor (IT13), Wearable device (IT14), Tracking system (IT15), Special equipment or machine (IT16), 3D Printer (IT17)	8, 9, 10

1: (Banihashemi et al., 2017), 2: (Rahdari et al., 2016), 3: (Ozorhon & Oral, 2017), 4: (Naoum & Egbu, 2016), 5: (Akmam Syed Zakaria et al., 2018), 6:(Adabre et al., 2021), 7: (Kornilov et al., 2020), 8: (Patel & Padhya, 2021), 9: (Moghayedi et al., 2021), 10: (Li & Liu, 2019)

4. Results and Discussions

Table 2 summarized the characteristics of 517 home developers' companies participating in the current research and their housing project characteristics.

As indicated in Table 2, most home developers' size companies belong to small and micro with minimal experience in designing and constructing affordable housing, which is common across developing countries (Pablo and London, 2020). The project characteristics indicate the robust role of private developers in affordable housing projects since many affordable projects developed using traditional project delivery. However, integrating sustainability and innovation in projects, particularly in the construction stages, is significantly challenging due to the difficulty of amendment in this type of procurement by construction teams (Kavishe, Jefferson & Chileshe, 2019).

Table 2. Company and housing project characteristics

Company characteristics	Establishing	>20 years 12%, 11 - 20 Years 26%, 6 - 10 years 34%, < 5 years 28%
	Relevant experience	High 17%, Moderate 29%, Minimal 50%, No experience 4%
	Company size	Large 12%, Medium 18%, Small 39%, Micro 31%
	Awareness and familiarity with sustainability and innovation	High 25%, Moderate 40%, Minimal 24%, No familiarity 11%
Project characteristics	Project size	Large (more than 20units) 14%, Medium (11-20 units) 27%, Small (5-10 units) 34%, Very small (less than 5 units) 25%
	Project client	National government 15%, Local government 20%, Private 65%
	Housing type	Mixed 26%, Apartment 14%, Semi-detached 33%, Detached 27%
	Project procurement	Conventional 41%, Design and Build 27%, Management contracting 24%, Others 8%

The Relative Score was utilized to calculate the level of adoption of various methods, materials and technologies by developers in 517 samples size of affordable housing projects.

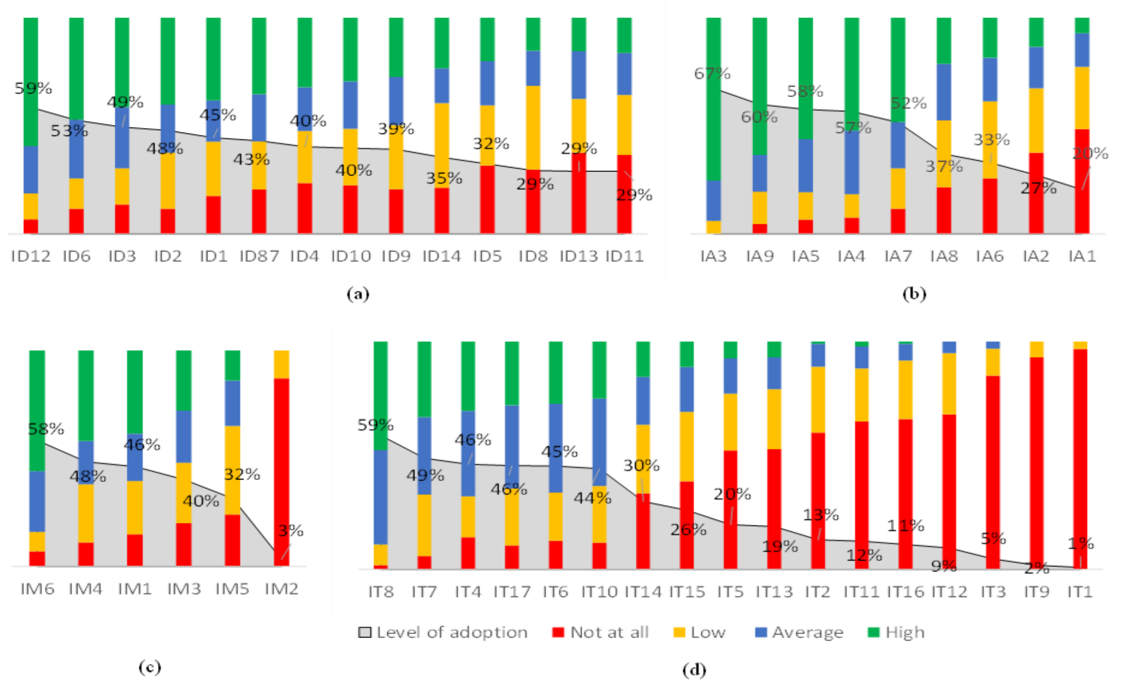


Fig. 2. Level of adoption of (a) sustainable design methods, (b) alternative construction methods, (c) sustainable materials and (d) new technologies

As shown in Figure 2 (a), most developers ignored sustainable design methods such as integrating renewable energy and life-cycle carbon footprint that affect the operation of houses to minimize the development cost of units. On the other hand, the results of alternative construction methods (b) disclosed that most developers adopted resources efficiency methods, which because of the increased consideration around the integration of environmental sustainability in the construction industry as well as the high price of energy and water in South Africa (Moghayedi et al., 2021). Adopting sustainable materials (c) indicates that most developers use building materials available in the local market with lower transportation and hauling costs (Adabre & Chan, 2020). However, as shown in Figure 2 (d), the level of adoption of new technologies in South African affordable housing projects is relatively low. This finding aligns with the Patel and Padhya (2021) findings, which stated that technology adoption in housing projects in developing countries is considerably limited. This slow adoption may drive by the lack of knowledge and the high cost of these new technologies (Adabre et al., 2021). However, the high level of adoption of some technologies, such as drones, is due to developers' awareness of the potential advantages of drones in monitoring projects and the minimal cost and skill required for purchasing and operating a drone (Li & Liu, 2019).

4. 1 Causal Model of SIAH

Ultimately, to validate the developed casual model is tested using collected data from registered low-cost housing developers in South Africa. The internal consistency, composite reliability and convergent validity test results show good internal consistency between the variables under the same constructs (0.7<α<0.95). Before analyzing the causality model, three hypotheses were tested using T-Statistics. P-Values of the hypotheses test are less than 0.05; therefore, all research hypotheses are statistically significant. Thus, the results of the research hypotheses tests validate the developed SIAH causal model of the study. Based on the hypotheses testing results, the study deduced that the influential internal factors (company and project characteristics) have a low positive (0.448) impact on adopting technological innovation in affordable housing projects. In contrast, the influential external factors have a moderate negative (-0.573) impact on the adoption of technological innovation in affordable housing projects. Furthermore, the indirect impact testing of the research hypotheses proves that the influential external factors negatively mediate the impact of influential internal factors on the adoption of technological innovation in affordable housing projects. Therefore, the total impact of influential internal factors was significantly reduced, as shown in the final causal model of SIAH in Figure 3.

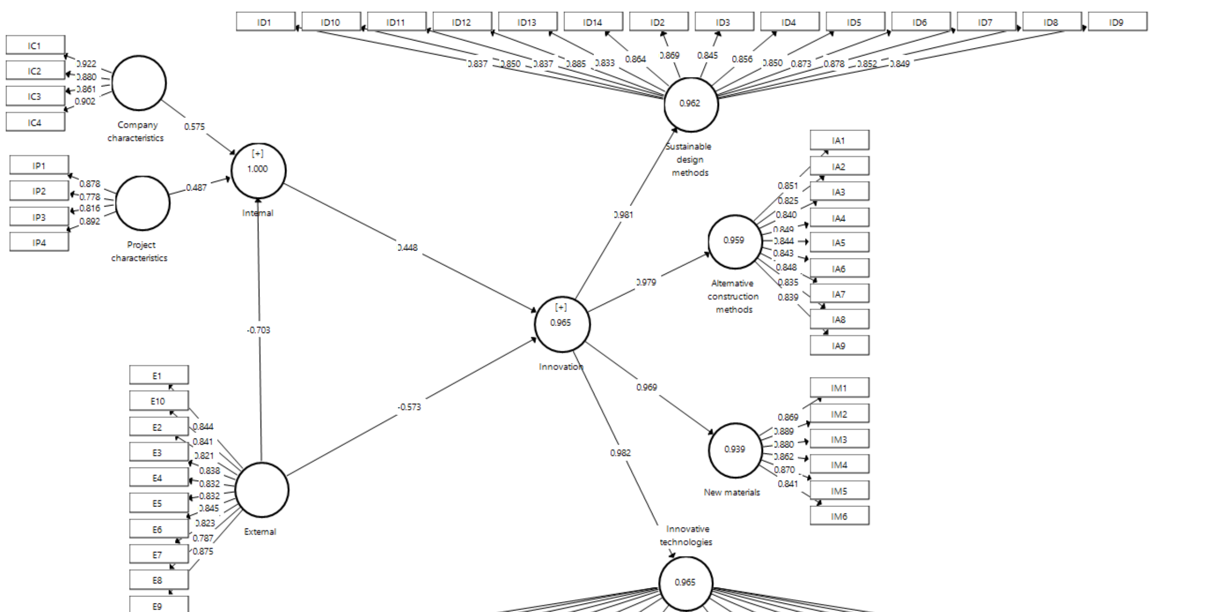


Fig. 3. Path analysis of the causal model of SIAH

As shown in Figure 3, sub-constructs and variables are highly linked to their relevant constructs (loading factors>0.8), proving a high nexus between variables and sub-constructs in the reflective measurement of constructs in the developed casual model. The positive associations among internal factors (company and project) and adoption of innovation of technological innovations in affordable housing projects directly depend on the company and project size, the relevant experience in affordable housing projects, technical staff awareness and familiarity with sustainability and innovation, housing types, project client and project procurement. The total effect coefficients model results also validated that the level of innovation adoption of technological innovations directly and indirectly (through internal factors) depends on ten identified external factors. However, comparing the level of impact of two constructs, internal (0.448) and influential external factors (-0.573), proved that the adoption of technological innovation and sustainability in affordable housing projects are strongly associated with influential external factors. The external factors as a key drive predominantly hurdle to adopting technological innovation and sustainability through direct and indirect effects. Moreover, the path analysis diagram (Figure 3) shows the high negative impacts (-0.703) of external factors on the influence of internal factors on innovation adoption. Therefore, it can deduce that adopting innovation and sustainability in affordable housing projects will significantly improve by reducing the influential external factors. This is due to both the direct negative impacts of external factors on the adoption of technological innovations and the negative mediator impact of these factors on the association between influential internal factors on the level of adoption of technological innovation. These findings are aligned with previous scholars who acknowledge that the external factors (challenges) are the most influence on the level of adoption of innovation in construction projects and particularly housing projects (Jamaludin et al., 2018; Moghayedi et al., 2022; Patel & Padhya, 2021).

Lastly, the outer weights of dependent variables revealed that relevant experience (IC2), awareness and familiarity with sustainability and innovation (IC4), company size (IC1) and company establishment (IC3) are the most crucial company characteristics, respectively, whilst the housing type (IP2), project size (IP1), project client (IP3) and project procurement (IP4) are the most effective project characteristics. Considering the moderate negative impact of external factors, the variables under this construct influence the adoption of innovation and sustainability in affordable housing projects. As shown in Table 8, the high cost of methods and technology (E1) is the external variable with the most negative effect on adopting innovation and sustainability in affordable housing projects; this finding is supported by Adabre et al. (2021). Furthermore, low availability in the local market (E10), lack of incentives (E5), tendency to use conventional methods, materials or technologies (E4) and lack of technical knowledge (E6) are the other most predominant barriers that hurdle the adoption of innovation and sustainability, these findings verified by the study of Moghayedi et al. (2022) and Adabre et al. (2021). Overall, the Outer weights of variables of the two constructs are relatively close, which indicates the importance and effect of all selected variables on the adoption of innovation and sustainability in affordable housing projects.

5. Conclusions

The study investigates the influential internal and external factors and the level of adoption of innovation and sustainability in affordable housing projects in South Africa. The current research establishes the existence of causality and effects between these constructs. Furthermore, it validates their impact on the adoption of innovation and sustainability in affordable housing projects by empirically scrutinizing the relationship between internal and external variables and the adoption of technological innovations. The findings from the study have indicated that the adoption of innovation and sustainability in affordable housing projects is negatively associated with external variables and positively related to internal variables. Therefore, the adoption of sustainability and technological innovations in affordable housing should be increased to address current affordable housing issues and enhance the sustainability of housing and residents' quality of life. Hence, the awareness, opportunities and advantages for adopting innovation and sustainability in affordable housing must spread among all participants in affordable housing projects. Sustainability and innovation will disrupt affordable housing delivery and the business environment; hence, the housing stakeholders must adapt housing sectors to the changing dynamics. The study has contributed a framework for enhancing the sustainability and innovation in affordable housing as a cleaner production through integrating sustainable design methods, alternative construction methods, sustainable materials and new technologies in affordable housing projects and addressing the existing challenges.

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Exploring Data Science Applications for Construction Project Performance in the South African Construction Industry

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Abstract

Construction projects create vast amounts of data which is produced throughout the project's lifecycle in the form of building plans, schedules, cost estimates, bills of quantities and variation orders, etc. Data science has the potential to enhance processes like project delivery, decision-making, equipment and personnel management, transparency, and communication. Hence, it has been noted as an upcoming technology that could assist the construction industry in meeting the data increase. Despite the significant benefits associated with the implementation of data science, the South African construction industry (SACI) continues to have problems with budget overruns, time delays, and the project being delivered below quality standards. Thus, the aim of the paper was to investigate data science applications for construction project performance in the SACI. The research was carried out using the quantitative approach through a well-structured questionnaire that was distributed to construction professionals in South Africa (SA). A total of 55 responses were received from the participants, and the data were analysed using descriptive statistical procedures using the computer software SPSS. The study disclosed the major applications of data science for construction project performance to be in tracking construction equipment and assets, project cost management, and operations and maintenance. The research findings prove that there is still a low adoption of data science for all facets of construction project performance as construction equipment and assets, project cost management as well as operations and maintenance relate to cost performance not quality and time performance.

Keywords

Construction project performance, Data Analytics, Data Science, Predictive Analytics, and Project Delivery.

1. Introduction

In the age of disruptive digital technologies, the rate at which data is accumulated has rapidly increased (Munawar *et al.,* 2022). This increase in data has not spared the construction industry (CI), in fact, Aghimien *et al.* (2019) strongly believe that the amount of data that is generated during the delivery of a construction project and the use of traditional tools for data analysis have made it difficult to make sense of this data. Furthermore, Tang *et al.* (2017) suggest that the exponential increase in the amount of information that is exchanged on a daily basis from multiple electronic devices such as cell phones, computers, cameras, laser scanners, and laptops has contributed immensely to the inundation of data in the construction industry (CI). Xu *et al*. (2020) postulate that poor planning, budgeting, cost overruns, miscalculations, insufficient funding for the project, low return on construction assets, and poor quality control are some of the challenges that have always affected the CI.

The nature of the CI is such that large amounts of construction information is generated throughout the lifespan of a project (Bilal *et al.,* 2019). Typically, this information is conveyed verbally or through written materials on paper, including 2D drawings. Cheng and Teizer (2010) note that traditional methods of delivering information have not always been able to make speedy and accurate decisions due to inadequate or poorly written data. The need for data science in the CI resulted from various construction stakeholders and researchers trying to gain value from this data and for construction companies to improve the overall project performance and increase profits (Renukappa *et al.*, 2021). Hence, the purpose of the study is to assess the applications of data science for construction project performance to improve the adoption of data science in aiding project delivery in the SACI. The findings of this study will create awareness among construction professionals where data science can be applied to aid with the current challenge of a data-intensive industry (Aghimien *et al.,* 2019). This paper will also contribute to the body of knowledge of data science in the CI.

2. Data Science

Data Science as a concept was first introduced in the mathematics and statistics field, which at the time only focused on data analysis (Cao, 2017). According to Xu *et al.* (2020), data science was first discovered in the 1960s. During this period, the term "datalogy" was commonly used, which was defined as the science of processing data (Hwang and Chen, 2017). However, Xu *et al.* (2020) note that this concept gave data processing status in the science community and gave origin to the "data science" field as we commonly know it today. The exponential growth of data science has been accelerated in recent years by the rise of the 4IR, rendering it a universally recognized emerging field (Ram *et al.*, 2019).

In recent years, data science has been gaining traction and attention and is being widely adopted in various industries such as banking, automobile, manufacturing, healthcare, etc. (Xu *et al.*, 2020). The field has gone beyond specific areas such as data mining and machine learning, which is attributed mainly to technological advancements and research efforts in developing advanced analytics, cultivating new algorithms, and improving data models (Cao, 2017). According to Cao (2017), data science is a field that consists of research efforts from different disciplines that create innovations to move beyond the discipline, which basically draws and recreates a variety of pertinent disciplines and sources of knowledge, such as mathematics, communication, statistics, computing, informatics, sociology, and management. A definition by Martinez *et al.* (2021) suggests that "data science is the intersection of computer science, business, engineering, statistics, data mining, machine learning, operations research, six sigma, automation, and domain expertise".

While a study by Hwang and Chen (2017) notes that data science is a sector that necessitates managing the massive volume of data (text, audio, images, and files) and uses it for creating prescriptive, prescribed and expected rational models. Therefore, based on the aforementioned definitions, there is an overall agreement that data science seeks to effectively look into the complex nature of data to extract value for the business. The professionals who are tasked with analyzing and processing this data to solve problems and to extract value are known as data scientists. Due to the high demand of this skill, there has been a growing interest in defining the work carried out by data scientists. According to Martinez *et al. (*2021), a data scientist manages everything from gathering data to processing it in detail and visually and presenting the data in an understandable manner. In contrast, Warden (2011) describes a data scientist as someone who excels at software engineering and statistics more than any other engineer. Data scientists seek to transform raw data to information, information to a source of knowledge, and from knowledge to decision-making (Xu *et al.*, 2020). According to Hwang and Chen (2017), the field of data science serves as the cornerstone for big data, providing the essential tools for its analysis and processing as well as a practical strategy for maximizing its potential. Furthermore, Hwang and Chen (2017) note that data science skills are needed to solve problems affecting the CI for the longest time and make building easier at all levels. In addition, Liu (2017) and Xu *et al.* (2020) note that construction organisations can use the value of data science and data scientists to manage and enhance construction sites and for problem-solving processes and systems via data-driven techniques.

3. Applications of Data Science in the Construction Industry

In SA, data science tools are employed in various construction project phases (Aghimien *et al.*, 2018a). Data science uses data analytics software to systematically evaluate patterns and to extract meaningful insight from data. The outcome of the results gathered from the data analytics is used by organisations to improve their operations, improve project delivery, increase profits, and gain a competitive advantage over their market rivals (Renukappa *et al.*, 2021). Munawar *et al.* (2022) note that for a construction company to be successful in the age of data science, companies need to embrace data science to combat some of the challenges that have been hindering the growth of the CI. Tjebane *et al.* (2022) posit the view that the SACI is one of the least digitized industries compared to other industries. Bilal *et al.* (2019) attributed this low adoption to a number of factors. Amongst others, the degree of complexity, the size of the project and the number of stakeholders involved were identified as some of the major factors hindering the adoption of technology applications in the CI.

However, the advent of the 4IR has also positively affected the CI and in adopting data science in its operations (Aghimien *et al.,* 2018b). Data science is needed to solve these issues and make building easier at various phases. Construction companies use the value of data science to manage and enhance construction sites. Furthermore, Cote (2021) notes that data science can be utilized to comprehend behaviors and procedures, develop algorithms for processing massive volumes of data quickly and efficiently, enhance the safety and confidentiality of sensitive data, and offer recommendations for data-driven decision-making. This paper will dissect the areas where data science is applied in the CI.

Data science can play an essential role in construction health and safety by detecting risky patterns or behavior, and safety hazards with real-time data analytics before an accident can occur (Liu, 2017). Moreover, Liu (2017) goes on to say that data science in the CI can also be used to reduce accidents on-site. Through predictive analytics, construction professionals can forecast common accidents before they occur. As a result, worker injuries and related costs are reduced. To make precise predictions of incidents, predictive analytics depends on data from previous safety occurrences and a deep understanding of the business and its operations (Zhang, 2020). These estimations cover both workers and equipment as well as the environment. A study conducted by Oracle (2021) revealed that most AEC companies are looking into predictive analytics to enhance project delivery and reduce risks. According to Sivarajah *et al.* (2017), the ability to foresee future events using both current and previous data is at the core of predictive analytics. Predictive analytics use methods like statistical modelling and machine learning to generate predictions about the future, this has been game-changing for the CI mainly because of its ability to track raw data and transform it into meaningful information which can be used for prediction (Oracle, 2021). According to Sivarajah *et al.* (2017), the construction team can use predictive analytics to swiftly identify potential issues and rank them according to likelihood before selecting when to handle them. According to Xu *et al.* (2020), predictive analysis allows the contractor to make smarter decisions when bidding and budgeting a project. Contractors can avoid losses due to on-site conditions or design errors by analysing past project data prior to establishing an estimate. By using multiple scenarios insights can be applied to make estimations and avoid failures in the future. By acting proactively, the construction stakeholders can avoid additional costs, delays and accidents caused by dealing with changes to the design and schedule (Sivarajah *et al.,* 2017). Furthermore, Zhang (2020) notes that predictive analytics provide organisations a chance to investigate the future which allows construction professionals to mitigate risk unlike any other tools available on the market.

The process of cost optimization is a procedure that must be done throughout the lifespan of a construction project. According to Lu (2019), project cost management involves estimating, budgeting, planning, managing, financing, controlling, and funding so that the project's success parameters can be met, which are the project being finished on budget and on time. The use of AI systems in conjunction with data science in construction projects can allow the construction team to plan their activities and estimate appropriate costs on the project (Phaladi *et al*., 2022). Intelligent AI-powered tools and trackers assist in centralizing financial data, receipts, criteria, restrictions, and documentation while also analyzing expenditures in real time (Motau and Kalema, 2016). Data science tools will then automatically break down the construction process and schedule the construction activities (Phaladi *et al*., 2022). In addition, data science is becoming an essential part of workforce management (Ismail *et al*., 2018). The increase of mobile technology has made it easy to track worker and equipment movements on site (Bello *et al.*, 2021) and contractors can estimate when maintenance or updates are required utilizing data analytics tools now that mobile technology is starting to have predictive capabilities. Real-time adjustments can be made and applied across the job site thanks to this mobility, which boosts productivity and optimizes time management for the best possible product output (Gotthardt *et al.,* 2019). According to Motau and Kalema (2016), by forecasting future requirements based on past project experiences, data science can increase efficiency and make important resources and information easily accessible when needed. Mobile technology can help supervise technicians on construction sites, update and analyze crucial paperwork in real time, and make real-time modifications to schedules or project scope (Bello *et al.,* 2021).

According to Mathenjwa (2020), there can be information and data gaps when working with subcontractors, such as hindered visibility into their activities on the clock. Data Science software ensures that information collected on subcontractor activities is analysed to monitor subcontractors and ensure that they are compliant and perform their duties according to the contract (Ismail *et al.,* 2018). Through data analytics, design and schedule details are automatically recorded to avoid disputes, according to Bello *et al.* (2021), this is done to ensure accountability among various subcontractors. Secondly, according to Ismail *et al.* (2018), data science encompasses predictive analytics, which is a software development responsible for BIM simulation. BIM simulation helps the project team to view an entire project prior to the actual commencement of the works, taking collaboration between all the stakeholders involved to greater heights. Design clashes can be easily identified through prediction, helping the contractor avoid possible problems in the erection, operation, and maintenance. Furthermore, Sibiya *et al. (*2015) note that infrastructure projects need close monitoring of all activities, and the contractor must complete the project on schedule, within the allocated budget, and to the highest standards of quality and safety. According to the Luthuli (2019), data science technologies can also be used to retain vital information about the building site and to monitor actions taking place there, such as workers who are not productive during working hours or who are not wearing protective gear.

Construction asset management and tracking are critical for successful construction project performance (Itemit, 2021). For construction fleets, reporting on essential preventative maintenance reduces the possibility of breakdowns or equipment problems (Aghimien *et al.,* 2018a). Installing a Global Positioning System (GPS) in construction equipment which is used to track the exact location of the organisation's equipment is essential in monitoring and controlling equipment on site (Itemit, 2021). The tracking device uses GPS to communicate with a satellite to triangulate its current position. These technologies aid in managing and allocating costs as well as tracking the equipment inventory in real-time. Equipment and personnel tracking may be beneficial in preventing theft and equipment loss (Phaladi *et al.*, 2022). On the other hand, general contractors can identify areas for improvement and produce more accurate estimations by monitoring the performance of subcontractors during the project's execution phase (Ismail *et al.*, 2018). According to Barker (2020), the client benefits from optimized contractor performance in gaining better value through quicker turnaround times; higher-quality interactions; safer work environments; effective utilization of resources; less wastage of time and money; and significantly efficient use of project funding in the project. However, Rhumbix (2021) notes that you can jointly measure contractor performance and maximize efforts by utilizing data analytics. Therefore, data analytics can assist in determining the degree of performance of the contractor and highlight areas that could want improvement (Oncioiu *et al.,* 2019).

Risk analysis and risk management are top of the list when it comes to successful project delivery and ongoing operations. Planning, identification, monitoring, classification, response analysis, and numerous other factors go into managing processes and risks (Rhumbix, 2021). Analysis of risks determines the potential pitfalls in future resources, results, and impacts. Meng *et al.* (2022) claim that by creating a probability density function and construction cost through a comparison of data for a proposed project and a previous project that is similar to the one being planned, the risk analysis framework can calculate the likelihood-cost interval for a planned project's final estimate. Furthermore, Rhumbix (2021) notes that by examining factors affecting project risks, the data analytics model develops probabilistic estimates of project costs. In this model, data from the relevant region are gathered and analyzed in comparison to the data for a prior similar project before the planned project is implemented. Lastly, operations and maintenance are the final stage of the construction process. After construction is complete, construction data is gathered and saved for later use throughout the building's life cycle. According to Tejjy (2022), the building information can be used by the maintenance crew to carry out repairs and maintenance on the building. Munawar *et al.* (2022) suggest that construction-related data can be used to guide future renovation projects and give maintenance teams structural information. Furthermore, Wilcock (2022) asserts that data analytics are important post construction operations and maintenance. Ismail *et al.* (2018) argue that you won't be able to choose and track KPIs, set realistic targets, and model a different and more lucrative future without the data necessary to analyze past performance, identify issues and forecast probable results. The areas for data science applications for construction project performance in the SACI are summarised in table 1. The data science tools that are most commonly used in the industry are Geographic Information Systems (GIS), Building Information Modelling (BIM), and the Internet of Things (Rhumbix, 2021).

Table 1: Applications of Data Science in the Construction Industry

S/N	**Application Areas of Data Science in the Construction Industry**	**Authors**
1	Construction Health and Safety	Zhang (2020) and Liu (2017)
2	Predictive Analytics	Oracle (2021); Xu *et al.* (2020); Zhang (2020) and Sivarajah *et al.* (2017)
3	Project Cost Management	Phaladi *et al*. (2022); Lu (2019) and Motau and Kalema (2016).
4	Workforce Management	Gotthardt *et al.* (2019); Bello *et al.* (2021) and Ismail *et al*. (2018).
5	Subcontractor Performance Analytics	Mathenjwa (2020); Bello *et al.* (2021) and Ismail *et al.* (2018)
6	Construction Planning and Modelling	Luthuli (2019); Ismail *et al.* (2018) and Sibiya *et al. (*2015)
7	Tracking Construction Equipment and Assets	Phaladi *et al.* (2022); Aghimien *et al.* (2018a); and Itemit (2021)

8	Optimizing Contractor Performance	Barker (2020); Rhumbix (2021); (Oncioiu *et al.*, 2019) and Ismail *et al.* (2018)
9	Risk Assessment Optimization	Meng *et al.* (2022) and Rhumbix (2021)
10	Operations and Maintenance	Munawar *et al.* (2022); Tejjy (2022); Wilcock (2022) and Ismail *et al.* (2018)

5. Research Methodology

For this study, the quantitative approach was considered appropriate. As Queirós *et al.* (2017:371) define a quantitative research approach as a well-structured theoretical framework that collects data which is a comprehensive view of the population where the analysis of the numerical data will be done through a statistical procedure. Through statistical processes, data can be validated and tested. It is for this reason that a quantitative approach was utilized to gather empirical data for this study. This study was done in Johannesburg, South Africa, Gauteng Province. This is due to its central location and since it has a large concentration of construction companies. The target population in this study consisted of construction professionals registered with various professional bodies and actively practicing in the construction and property industries in South Africa.

A well-structured questionnaire was distributed to the respondents in the target population, this is important for the study as it will reflect the true reflection of data science adoption in the SACI. The respondents consisted of architects, data scientists, facility managers, construction managers, building managers, project managers, engineers, and quantity surveyors from the public and private sectors. A total of 55 responses were received, and they were all usable. Statistical Package for Social Science (SPSS) and a Microsoft spreadsheet were used to analyze and interpret the results.

The SPSS program allowed for the recording of original data to determine the mean item scores, standard deviations, ranks, and Cronbach's alpha, both SPSS and Microsoft Excel were used to create the graphs and charts. The reliability of the study of the study was tested via internal consistency. Where Pallant (2020) defines internal consistency as the degree where variables of the same scale correlate with each other which is often assessed by Cronbach's Coefficient Alpha. The coefficient is effective in research studies where the Likert scale was used for responses. The range is from 0 to 1, and a Cronbach's Alpha score of 0.7 is considered to be an acceptable reliability coefficient as the higher the value, the greater the reliability (Pallant, 2020). The Cronbach's Alpha value for the application of data science for construction project performance in the SACI was 0.946, which proves the reliability and validity of the questionnaire.

6. Research Findings

6.1. Demographic Characteristics of the Respondents

The majority of the respondents to the questionnaire were females sitting at 60%, while 40% were male, with more than 50% of the participants older than 26 years old. Figure 1 shows the various professionals who participated within the sample; architects, data scientists, and building managers specified others contributing 34% of the respondents.

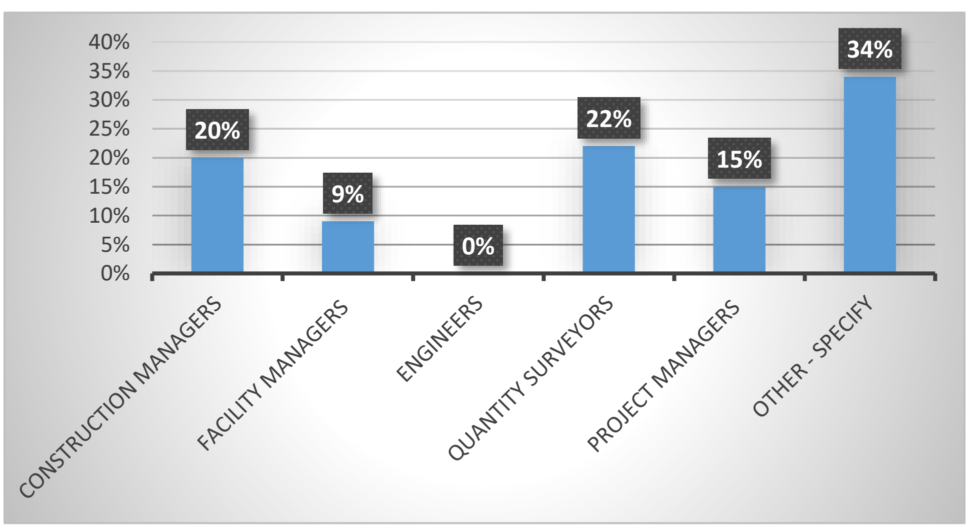

Figure 1 Respondents' occupational status

6.2. Descriptive Analysis on the Applications of Data Science in the Construction Industry

The participants were asked to indicate where data science is applied mostly in the SACI using a 5-point Likert scale of ‘Strongly disagree’ to ‘Strongly agree’ on the questionnaire. Table 1 shows the results relating to the applications of data science uptake in the SACI. Based on the rankings, the top five applications of data science in the construction industry are in tracking construction equipment and assets, project cost management, operations and maintenance, risk assessment optimization, and construction planning and modelling.

Table 2: Applications of data science in construction

Applications of data science in SA construction industry	**MIS**	**SD**	**R**
Tracking construction equipment and assets	3.98	1.209	1
Project Cost Management	3.95	1.177	2
Operations and Maintenance	3.93	1.215	3
Risk Assessment Optimization	3.91	1.159	4
Construction planning and modelling	3.89	1.242	5
Construction health and safety	3.87	1.171	6
Optimizing Contractor Performance	3.87	1.233	6
Subcontractor performance analytics	3.80	1.078	8
Workforce Management	3.78	1.182	9
Predictive Analytics	3.75	1.040	10

MIS = Mean Item Score, SD = Standard Deviation, and R = Rank

7. Discussion

Based on the respondents' average rating of the variables, the findings revealed a low level of adoption of data science in construction project performance in South Africa. The results are in agreement with studies conducted by Renukappa *et al.,* (2021); Aghimien *et al.,* (2018b), and Oracle (2021), which indicated the low-level adoption of data science. Despite the significant benefits associated with the adoption of data science, the CI is still lagging behind compared to other industries such as the automobile, finance, and healthcare industries (Ram *et al.,* 2019). The top three data science applications used for construction project performance in the SACI were in the tracking of construction equipment and assets which was ranked first, project cost management which was ranked second and operations and maintenance ranked third. These results do not agree with studies conducted by Bilal *et al.* (2019) and Ram *et al.* (2019), which ranked predictive analytics, Augmented Big Data and BIM integration as the most used big data applications in the CI.

Nevertheless, studies conducted by Bello *et al.* (2021) suggest that the most usage of data science is in the GPS tracking system aiding in monitoring and controlling equipment on construction sites. This is in agreement with the participant's response ranking tracking of construction equipment and assets first. Project cost management, the second-ranked application of data science, supports the findings of Phaladi et al. (2022) who point out that the utilization of AI technologies in collaboration with data science can bring out realistic cost estimates and well-structured construction programme. The respondents ranking third operations and maintenance is in agreement with Wilcock (2022), who asserts that data analytics are essential to post-construction operations and maintenance.

8. Conclusion

The findings in relation to the literature revealed that the research participants believe that tracking of construction equipment and assets, project cost management and operations and maintenance to be the top three applications of data science in the construction industry than subcontractor performance analytics, workforce management and predictive analytics which were the least ranked applications. There is a lack of awareness of data science applications in the industry, but this study focused only on the application areas in construction companies in Gauteng, SA. The government can increase this awareness by introducing stringent regulations promoting data science in public-sector construction projects.

The reviewed literature revealed that there are numerous applications of data science in the CI. It was noted from the literature the various data science that can be used in the CI. These included facilities management, risk assessment optimization, social media analytics, project cost management, data visualization, energy management analytics, operations and maintenance, performance prediction, generative design and tracking construction equipment and assets. The areas for further studies might look at the use of predictive analytics in improving project delivery in the construction industry.

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US Army Corps of Engineers: Improving HVAC System Commissioning Specifications to be More Efficient

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Abstract
The objective of this research is to help improve US Army Corps of Engineers (USACE) HVAC system commissioning specifications to be more efficient. Depending on who is asked, many say commissioning is a struggle for the USACE or some may say it is not. In the research process we will look at the engineering regulations ER 1110-345-723 and specifications UFGS 01 91 00.15 20 and how it is used by USACE. The questions in this research paper are: does USACE struggle with commissioning in general, and does USACE struggle with commissioning HVAC systems and does it stem from the specifications? Eight individuals throughout USACE were sent the list of questions then interviewed. From the interview process we can find some answers to the questions. The hope it to determine if USACE struggles with commissioning of HVAC is from the specifications or if the struggle is from other factors and using that information to help improve on USACE's commissioning of HVAC. The results, all those interviewed agreed that the struggle with commissioning was not with the specifications but with other factors. The questions sparked discussions on why it seems USACE struggles with commissioning from needing involvement of the commissioning team to the complexity of the systems.

Keywords
HVAC, Commissioning, USACE, ER 1110-345-723, UFGS 01 91 00.15 20

1. Introduction

The US Army Corps of Engineers (USACE) is responsible for design and/or construction of all Military Construction Army (MCA) and projects in support of others (. i.e., other military services and Department of Defense (DOD), Federal agencies, and vertical construction for USACE civil works projects) in the Continental United States and Outside the Continental United States (CONUS/ OCONUS). USACE involvement in a project is from initial design to final construction and turn over to the costumer. This includes commissioning on all projects. USACE reviews and approves all submittals and test reports for commissioning and witnesses all the testing required during commissioning. Commissioning is always a topic of discussion not only in the Walla Walla District but throughout the districts within USACE. Some of this discussion pertains to the commissioning of Heating, Ventilation, and Air-Conditioning (HVAC) systems. Depending on who you talk to there are various opinions on if the commissioning of the HVAC systems is completed correctly or if they are not. USACE goal for design is for the project to last for many years. Commissioning is an important part of a successful project for USACE when commissioning is done right, there is a confidence that a project is being handed over to a customer on a correct path for maintaining that project for years to come. But with changing of industry, that goal is becoming harder to maintain. Commissioning is one-way USACE can help make sure that goal is achieved. In order to achieve this goal, it starts with having the right specifications for commissioning and to do this the Project Delivery Team (PDT) needs to discuss commissioning earlier in the design process.

2. Research Objective, Background and Methodology

2.1 Research Objective

The objective of this research paper is to help improve USACE's HVAC system commissioning specifications to be more efficient. In order to help improve efficiency of the specifications one needs to know how the specifications are put together. What policies and guidelines are there for USACE to follow for commissioning HVAC? What format is used for the specifications? When we understand the specification, we can determine if the struggle with commissioning HVAC is based off the specification or if there are other driving factors. If USACE is struggling because it of the specifications, why? Does it lay with policies and guidelines? Does it lay with the standards in the specifications?

Answering these questions, we can provide some insight on the struggles with commissioning HVAC and help improve on USACE's HVAC system commissioning specifications to be more efficient. In effect helping USACE in becoming a stronger and efficient Agency when commissioning HVAC.

2.2 Background

What is commissioning: "Commissioning is the process of verifying that a building's heating, ventilation, and air conditioning (HVAC) and lighting systems perform correctly and efficiently and according to the design intent and owner's project requirements defined by the Department of Energy's 2011 Guide to Building Commissioning" (Baechler, 2011). How does this affect USACE? As mentioned above USACE is responsible for all MCA and support construction projects and that includes commissioning.

In February 2015, an Engineering and Construction Bulletin (ECB) came out that establishes the requirements for and provides information and guidance on Total Building Commissioning Processes on Army projects for Engineers, Project Managers and Construction Managers (ECB 2015-6). It reviewed the current ER 1110-345-723, Systems Commissioning Procedures and identified four tasks as new or needed augmented.

1. NEW: the designation of a USACE Commissioning Authority and supporting Commissioning team in the predesign/design phase
2. AUGMENT: design review process to include a commissioning review.
3. AUGMENT: the construction submittal review process by including the Commissioning Authority (or designated member of Commissioning team) review for systems being commissioned
4. AUGMENT: the warranty inspection with a Post Occupancy inspection by the commissioning team.

USACE, as the designated Commissioning Authority (CxA), is to provide oversight assurance of the entire commissioning process (ER 1110-345-723, 31 Mar 17).

USACE uses Engineering Regulations (ER) to develop the design for their projects. These ERs are written policies and guidance that are to be used when designing. One ER in particular is ER 1110-345-723, Systems Commissioning Procedures, dated 31 July 1995 (ER 1110-345-723, Systems Commissioning Procedures, 1995). The primary focus of ER 1110-345-723 was limited to commissioning of facility HVAC Controls (ER 1110-345-723, 31 Mar 17). In March 2017, ER 1110-345-723 was revised to total building commissioning procedures. This updated policy and guidance for developing total building commissioning procedures and executing/documenting commissioning activities for delivering facilities and systems starting with the planning phase and continuing through the post occupancy phase (ER 1110-345-723, 31 Mar 17). This was to capture all the commissioning activities through the life of the project, so the systems operated per owners' requirements and per the construction contract plans and specifications.

This brings in the specifications. USACE's specifications are derived from the Unified Facilities Criteria Program (UFCs) and the Unified Facilities Guide specifications (UFGS). The UFGS pertains to planning, design, construction, and operation and maintenance of real property facilities (WBDG, 2021). The Unified Facilities Criteria Program is to unify all technical criteria (WBDG, 2021). The UFGS covers several design processes such as Design-Build and Design-Bid-Build. Each USACE district handles projects and contracts differently depending on the scope of work, complexity, and in-house expertise. It also depends on if it is military construction or civil works. Military construction is predominantly Design-build whereas Design-Bid-Build is predominantly civil works. The UFGS format has three sections: general, product, and execution. Depending on the design of the project will depend on what sections are used.

The UFGS is the general specification for the contracts and the starting point. The specifications are what the work is to be done and, in this case, what commissioning is to be accomplished. There are three specifications to look at in the UFGC, Section 01 91 00.15 20 Total Building Commissioning, Section 23 05 93 Testing, Adjusting, and Balancing for HVAC, and Section 23 08 00.00 20 Commissioning of Mechanical (and Plumbing) Systems. These three general specifications are the starting point of the design and are tailored to the scope of work to be performed for each project. They pull in all the required standards needed for specific sections and the testing. Specification sections 23 05 93 and 23 08 00.00 20 deals with testing the equipment for HVAC and all the other equipment individually. Section 01 91 00.15 20 deals with testing all the equipment as a system.

2.3 Research Methodology

This research paper utilized the interview method to understand the USACE specifications for commissioning of HVAC. The specification this research paper will focus on is UFGS 01 91 00.15 20 for both Design-build and Design-Bid-Build. The plan is to interview nine individuals throughout USACE and get their thoughts for commissioning of HVAC, from initial design, specifications, construction and commissioning. By using the interview process, one should learn what Engineering Regulations (ERs) are being used and how ER's are used to draft the specifications for the commissioning of the HVAC system by means of UFGS 01 91 00.15 20. The interview process will be used to understand how specifications are used for the commissioning and what requirements are there for commissioning. During the interview process following three questions will be asked:

1. Does USACE struggle with commissioning in general?
2. Does USACE struggle with commissioning HVAC systems?
3. Does it stem from the specifications?

By gathering the answers from the interviewees, it should be determined if the struggle is from the specifications. The follow-on questions will be based off how the interview responded to the previous question. These questions are:

1. Why do you think that USACE struggles with in commissioning of HVAC systems: lack of experience, inefficient specifications, or both?
2. What do you think USACE can do to improve the process?
3. What does your district have in their specifications for commissioning HVAC systems? What specific standards are called out for commissioning?
4. Do you think if we improve on USACE specifications, it will improve on our commissioning?

If during the interviews, it is found that USACE does not struggle with commissioning of HVAC or does not struggle because of the specifications based of the question: "does USACE struggle with commissioning HVAC and does is stem from the specifications?" The follow-on questions will be based off how the interview responded to the previous question. The follow-on questions are:

1. What is being done right in your district? Is it something that can be used USACE wide?
2. Is there a specification section that could be improved on?
3. What does your district have in their specifications for commissioning HVAC systems? What specific standards are called out for commissioning?
4. Do you think the specifications have helped with commissioning HVAC systems?

From the results of the interviews, it shall be determined if USACE is struggling with commissioning HVAC systems and if it is or is not because of the specifications.

3. Results

This research paper interviewed eight individuals throughout USACE: Baltimore District, Hydroelectric Design Center (HDC) Mobile, Portland District, Walla Walla District, and Far East District – Korea. Five of the interviewees work in the design branch for USACE, one interviewee works in the commissioning section branch, and three interviewees work in construction branch. All the interviewees were asked the same three initial questions:

1. Does USACE struggle with commissioning in general?
2. Does USACE struggle with commissioning HVAC systems?
3. Does the struggle stem from the specifications?

There were varying responses to "Does USACE struggle with commissioning in general and does USACE struggle with commissioning HVAC systems?" Some saying yes that USACE struggles with commissioning and with commissioning of HVAC systems. While some responding that no USACE does not struggle with commissioning in general or with commissioning of HVAC systems. But all of them seemed to agree the struggle or not with commissioning was that it was not from the specifications or the standard that are referenced in the specifications.

When the specifications followed the ER 1110-345-723, Total Building Commissioning Procedures, commissioning of the HVAC system would be successful. Total Building Commissioning includes commissioning of a variety of building systems, not just HVAC systems, and establishes the required level of effort for commissioning on projects (ER 1110-345-723, 31 Mar 17). The exception is with buildings that are 5,000 GSF or less, then the use of ASHRAE 189.1, section Building Acceptance Testing, is sufficient. The Total Building Commissioning (TBCx) guidance is to involve Commissioning Authority (CxA) and the commissioning team early in the design process and keeping them involved through design, into and through construction. The CxA in this case is USACE and has the overall oversight but can assign responsibilities to other individuals. Reference Appendix A (ER 1110-345-723, 31 Mar 17).

The ER 1110-345-723 also explains the role of Commissioning Specialist for the Government (CxG), and Commissioning Specialist for the Design Phase (CxD), and Commissioning Specialist for the Construction Phase (CxC). It was brought up that it was key to have CxG and CxC. The CxG is the lead individual, employed by the Design and Construction Agent (USACE), but not affiliated with the construction contractor, and is responsible for government oversight of the commissioning process (ER 1110-345-723, 31 Mar 17). The CxC is the lead individual, employed by a commissioning firm, responsible for managing, scheduling, executing, and documenting commissioning activities for the duration of the construction contract and shall be employed by a commissioning firm that is a first-tier subcontractor hired by the construction contractor (ER 1110-345-723, 31 Mar 17). It was mentioned that CxG and CxC are not always assigned to projects for various reasons. The CxG may not be assigned to a project as some districts or area offices my not have a designated commissioning individual or section. In this case the lead engineer is to be assigned to assist in commissioning and in some cases, it is left to the onsite government Quality Assurance Representative (QAR) to be present for commissioning. In some cases, the commissioning firm is not always specified in the specifications. Then the CxC usually is the installer of the equipment that is leading commissioning instead of an individual of commissioning firm. Those interviewed all said having these individuals identified and involved early in the project would help in having a successful commissioning, though funding may play into what is specified for some districts.

The early involvement of the commissioning team was the key for most interviewed as it gets everyone talking about commissioning and what will be needed to commission not just the HVAC but the system. The specification section UFGS 01 91 00.15 20 Total Building Commissioning is the starting block for laying out how USACE wants to see from the contractor when commissioning. Even though most of the interviewees indicated that earlier involved of the commissioning team was a key, it was mentioned that having the full team involved is not always the case. Most cases the full team was involved earlier in the design but was not always involved in the construction phase. This seemed to be common for the districts that do not have a commissioning section branch and relay on their design engineers to be part of the commissioning team. Some interviewees had indicated they were the commissioning team. Many said listing the team and their roles during that early involvement is key, that there were times that they were not sure who was on the time and had what role and what their responsibility was. Keeping them engaged through the who process was a challenged as everyone may have several different projects going on and at different stages. Many times, once the project hit the construction phase involvement dropped off dramatically or was nonexistent. Some did mention that funding and schedule played a role in involvement. Some projects didn't have the funding for continuous involvement and had to watch the number of hours being charged. Most of the time leaving little time to be present for commissioning. Those that have experienced a commissioning team that was involved, commissioning of the HVAC was successful and commissioning in general was successful.

The UFGS 01 91 00.15 20 has two sections: general and execution. The product section is left blank in this specification. The general section lays out all the general requirements for communicating, the systems to be commissioned, and the commissioning team. This section specifies the details in what to include in a project schedule and the required submittals USACE wants to approve. The section covers the first-tier subcontractor, the commissioning firm, and the required specialist as mentioned in the ER 1110-345-723. The commissioning standards are also listed in this section. If the government is planning to use a third party for commissioning, it will be called out in this section as well. The section ends with the requirement for certificate of readiness. The certificated of readiness states "Prior to scheduling Functional Performance Tests, the Quality Control Manager must issue a Certificate of Readiness for each system, certifying that pre-functional checks have been completed, open issues have been resolved, and the system is ready for Functional Performance Testing" (UFGS 01 91 00.15 20, February 2021). This section covered one or more topics brought up by interviewee of items needed to have a successful commissioning. The key take-aways from the interviews, communication and certificate of readiness. Communication was mentioned in one way or another during the interviews and communicating through all phases of the project from design, constructions, and into commissioning. Some interviewees did say with commissioning very little to nothing was communicated on commissioning until the project was about ready or ready to commission. The reason why this was: everyone is focused on the construction of the project and making the contract completion date that commissioning is an afterthought. Another topic mentioned was the certificate of readiness. A requirement that is often missed or only partially completed. If completed or provided it is usually missing the results or documentation that shows that the systems were tested and are ready for startup. Again, the reason why this was: everyone is focused on the construction of the project and making the contract completion date that commissioning is an afterthought. The contractors are so focused on the construction that they fail to read the requirements for commissioning.

The execution part of the UFGS 01 91 00.15 20 should help the general section as it descripts the work to be accomplished during the commissioning process. This section lays out requirement for design commissioning coordination meeting (requirement for Design-Build), design phase commissioning plan, the design review, construction submittal, commissioning kickoff meeting, and regular commissioning coordination meetings. This section covers the construction phase commissioning plan and all the checklists that are required for the plan:

1. Template Building Envelope Inspection Checklists
2. Pre-Functional Checklists
3. Functional Performance Test Checklists
4. Integrated Systems Test Checklists
5. Building Envelope Inspection and Testing

All of which are required to be submitted with the certificate of readiness. The pre-functional checklist has its own paragraph that explains in detail what to check and who is to witness it. It even calls out to provide manufacturer start-up checklists associated with equipment with the submission of the Pre-Functional Checklists (UFGS 01 91 00.15 20, February 2021). There are sections for functional performance and integrated systems tests and a training plan. An important part of this section is Commissioning Report section. This section details what the contractor shall include in the commissioning report. The report shall include an executive summary, a list of any deficiencies discovered during commissioning and the corrective means for the deficiencies, and a completed copy of all the checklists, commissioning plans, training attendance rosters, design review reports, submittal review reports, and the approved Testing and Balancing (TAB) Reports. The execution part of the UFGS 01 91 00.15 20 is very detailed in its general form and should only get better when tailored to the specific project. The key take-aways from the interviews: the checklists and coordination meetings. The ER 1110-345-723 guidance was for the commissioning team's involvement throughout the project from initial design through construction. The UFGS 01 91 00.15 20 does that with coordination meetings. For Design-Build, the first meeting detailed is the design commissioning coordination meeting. "The purpose of the meeting is to discuss the commissioning process, including project contract requirements, lines of communication, roles and responsibilities, schedules, and documentation requirements (UFGS 01 91 00.15 20, February 2021). The specification requires for there to be two meeting held for the design, one is at 35 percent and one at 50 percent of the design. A follow-on meeting for Design-Build is the design phase commissioning plan. This plan is to "Outline the commissioning process, commissioning team members and responsibilities, lines of communication, and documentation requirements for the design phase of the project in the

Design Phase Commissioning Plan. Identify the Commissioning Standard chosen for the project (UFGS 01 91 00.15 20, February 2021).

The design review meeting is to be held once the contract is awarded. "The design review must include verifying the Design Plans and Specifications for the systems to be commissioned are prepared in accordance with the contract documents" (UFGS 01 91 00.15 20, February 2021). The commissioning kickoff meeting is to discuss the commissioning process for the specific contract. The discussion should include the contract requirements, lines of communication, roles and responsibilities, schedules, documentation requirements, inspection and test procedures, and logistics needed to complete the commissioning. This meeting is to be held early in the project normally some many days after the notice to proceed. For some districts this meeting is help so many days before the approved scheduled commissioning date.

The UFGS 01 91 00.15 20 requires regular commissioning coordination meetings. These meetings are to be held once the installation of the HVAC equipment has begun and be scheduled to happen monthly. This section requires bi-weekly meeting when the commissioning is with 30 days of the scheduled commissioning. The purpose of this meeting is to give the government commissioning team a status of the system to be commissioned, any issues, submittal status, and if any commissioning activities are coming up. The regular commissioning meeting was a topic of discussion during the interview process. The interviewee had some reserve if theses meeting were happening from some of the commissioning they had witnessed. The regular commissioning coordination meetings as drafted in the UFGS does not require the contractor to take or submit meeting minutes as it is required for other meetings called out in the specifications. It was mentioned that it would be nice to have the requirement for the contractor to submit the meeting minutes of the regular commissioning coordination meetings. In some cases, some districts have in their specification that the meeting minutes are to be attached to the contractor daily reports and to be uploaded into the Resident Management System (RMS). RMS is a quality management and contract administration program designed by Resident Engineers of USACE. But the UFGS does not require the contractor to submit the regular commissioning coordination meeting minutes as attachments to their daily reports. The interviewee that it would be going to have language in the specifications to document the regular commissioning coordination meeting and have it as a submittal or attached to the daily reports. This seems like an easy fix and one that can be addressed during the initial design phase. During the initial design phase, the commissioning team should be able to request the meeting minutes for the regular commissioning coordination meeting be recorded and then either be a required submittal or as an attachment to the contractor's daily reports. But remember earlier in the report the commissioning team could just be one individual reviewing the commissioning section and may have specific things they are looking for and meeting minutes may not be one of them. Requiring the meeting minutes to be recorded and submitted either as a submittal or attached to the daily reports as mentioned earlier, helped with the keeping individuals engaged and possibly raise questions even though they were not present for the meeting.

UFGS 01 91 00.15 20 listed a couple of commissioning plans and commissioning checklists. The design phase commissioning plan has two parts, the interim and the final. The interim commissioning plan should "identifies the commissioning and testing standards and outline the overall commissioning process, the commissioning schedule, the commissioning team members and responsibilities, lines of communication, documentation requirements for the construction phase of the project, and Template Building Envelope Inspection Checklists" (UFGS 01 91 00.15 20, February 2021). The final commissioning plan should the approved interim plan plus "the Pre-Functional Checklists, Integrated Systems Test Checklists, and Functional Performance Test Checklists for each building, for each system required to be commissioned, and for each component for inclusion in the Final Construction Phase Commissioning Plan" (UFGS 01 91 00.15 20, February 2021). The commissioning plan should be planned with seasons in mind as there could be requirements for testing for cooling and heating for the building.

As stated above, there are several checklists required to be completed. During the interviews while discussing the interview questions provided, a topic that came up was commissioning plans and checklist. As stated earlier, all the interviewees said the specification were not the issue for USACE struggle with commissioning in general or with HVAC. But it was the fact that many contractors failed to follow the specification specially when it came to checklists and commissioning plan requirements. That the contractor did not read the requirements for commissioning and did not realize what was all required to be provided. In many cases the checklist was not provided before scheduling commissioning. The commissioning plan in some cases was not provided for review until few days before the commissioning. Earlier involvement of the commissioning team doesn't mean that the contractor will follow the specification. More times than not USACE is left rushing to complete reviews of checklist and commissioning plans or left to start commissioning with partial checklists or commissioning plans still under review. Which many time results in rescheduling the commissioning because what the contractor said was completed on the checklist is now not working or was not tested to begin with.

Some of the interviewees said they had completed checklists and approved plans but when it comes to commissioning the contractor failed to have the individual assigned to commission the system onsite. The contractor had thought USACE would be doing the commissioning not just witnessing it. Which resulted in delaying or rescheduling the commissioning due to little or no communications. Some of these issues were addressed by some districts by having the third-party commissioning agent. But not all districts plan for that and in these cases USACE must be more diligent and involved not just in the earlier design but through construction by keeping track of when requirements due be present for the pre functional checklist activities.

Another topic of discussion when interviewing that came up was the commissioning reports. In most cases it was getting the contractor to submit them for USACE to review. The contractor would go through the checklists as required by UFGS 01 91 00.15 20, but the contractor would not record the results or if they did record the results only recorded certain results or just fail to submit the results. The UFGS requires an initial commissioning report and a final commissioning report. The initial report is just the commissioning team's validation of the Functional Performance Tests and Integrated Systems Tests. The final commissioning report is much more involved as stated previously. In many cases the reports submitted are incomplete and are returned unapproved. A failure of the contractor to read the specifications which from everyone interviewed if they followed the specifications, it clearly identifies what is required on the commissioning report.

Even though all the individuals interviewed agreed the specifications were not the reason that is seems USACE struggles with commission, the questions asked can USACE improve on the specifications, and would this help improve USACE's commissioning? Besides the requiring of the commissioning meeting minutes to be recorded.

There was one during the interview that mentioned that providing good examples of what USACE is looking for, has helped with commissioning. This went for the pre-functional testing, functional performance test checklists, integrated systems test checklists, and building envelope inspection and testing. Then the contractor had something to follow when they put their checklist together as required by the contract. Other than the two suggestions list above none of the other interviewee had any to add that if the specifications are followed commissioning should be successful.

There were a few that mentioned the complexity of the system being commissioned being a reason for the struggle. The ER 1110-345-723 was updated to commission the entire building system. One cannot just test the HVAC system on its own. That the HVAC is just one but of an entire system. Depending on the building there could be just a single unit to test were just doing the Testing and Balancing (TAB) and submitting that report would be acceptable to testing multiple units where all the pre-commissioning checklists need to be completed before commissioning of the system can being. The system could include (USACE sustainability, 2013 April 3).

1. HVAC
2. Building envelope
3. Protection systems as in Fire suppression or lighting protection
4. Plumbing
5. Electrical System as in power or lighting
6. Communication systems
7. Alarms

The systems today are all digital and require Programmable Logic Controller (PLC) run the system. Even when you have completed all the checklists, commissioning the system may indicate one or more subsystems may need adjusting and may require adjusting several times to balance the system and complete commissioning.

During the interviews it was mentioned that sometimes the design for projects seems to be excessive. A safety factor is usually built into the design but through the design process that safety factor is compounded to a point the equipment that is install is much larger than needed for the buildings and USACE designs usually have redundancies built in so now there is two pieces of equipment larger than needed that need to be commissioned. The example explain during the interview was with chillers. There were two chillers installed for a building that's full capacity may have used just 25% of the chillers capacity and the building had two of these chillers. Commissioning now has an added challenge as in some commissioning plans the equipment must be commissioned at 100% of its capacity which if the whole building only uses 25% now the commissioning plan must include a means of commissioning the equipment at 100% capacity. Subsequent paragraphs, however, are indented (here insert the second paragraph).

5. Conclusions

Commissioning extends through all phases of new or major renovation projects, from predesign to Owner occupancy and operation, with tasks during each phase to ensure verification of design, construction, and operator training (ASHRAE Guideline 0-2019).
This study discovered that the specifications is not the reason USACE seams to struggle with commissioning of HVAC or in general. There are many other factors one must look at when commissioning. How involved was the commissioning team assigned to the project, were their roles and responsibilities set was a major factor for a successful commissioning. Making sure regular commissioning coordination meetings are taking place and the meeting minutes are being documented. Include examples, when possible, for all the checklists that are required before commissioning. Following up with the contractor to make sure they are completing the checklists and are submitting them for review. Follow up with the commissioning team to make sure they are reviewing the submittals from the contractor and are providing their feedback. Doing as many of these things as possible will help making the commissioning HVAC a success.

Appendix A

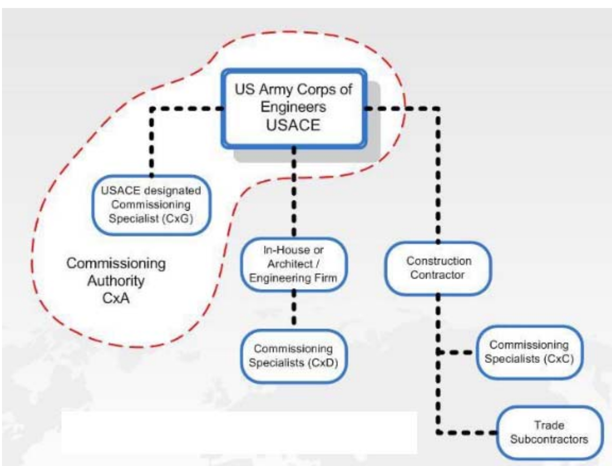

Figure 1. Design-Bid-Build (D-B-B) Commissioning Organization Chart (ER 1110-345-723, 31 Mar 17)

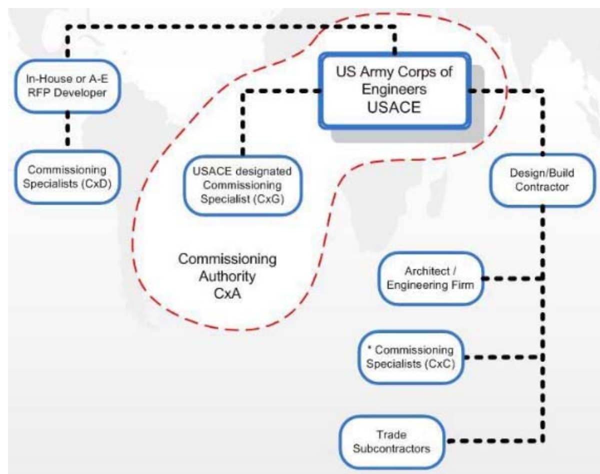

Figure 2. Design – Build (D-B) Commissioning Organization Chart (ER 1110-345-723, 31 Mar 17)

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VR as a Collaborative Design Tool for Urban Agriculture: An Alternative to Urban Map Walks Methodology

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Abstract
Urban agriculture has a long history in urban settlements. Once as a means of addressing food shortages mainly in the Global South, urban agriculture has now found a wider suite of purposes to fulfil, hence a greater momentum worldwide. Review of the existing literature indicated a growing body of research where different methodologies had been utilized to study the stakeholders' participation in urban community gardens. Despite the proven record of virtual reality (VR) technologies' role in facilitating design participation in other areas, no record of such research was found for urban agriculture. An analog methodology developed for urban agriculture, known as "Map Walks", was used as a basis to develop a VR-based digital walkthrough instrument aiming to concentrate on collaborative intervention in urban spaces, to add features and components associated with urban agriculture which were otherwise not achievable through the analog methodology. The two stage study opened up new horizons not only for the participants but also for the researchers as to how VR technologies can add more collaborative capacities in participatory design. The findings indicated that although it was found as an effective supplementary method to realize the impact of interventions in urban spaces, 1) proactive interaction with the application was key for all participants, 2) different users expected different things from the VR experiment, and 3) they responded to the use of technology diversely and not quite as per expectations.

Keywords
Virtual Reality, Urban Agriculture, Collaborative Design, User Experience, Map Walks

1. Introduction
Reculeau (2017) argues that agricultural activities in urban areas are as old as human settlements. However, the role of community stakeholder groups and their proactive participation have become more prominent in the success of public projects in recent years. Community garden (also referred to as urban gardening and urban agriculture) projects are classical examples where such participation has proven to be a substantial tool to document and make effective use of community level input thereby increasing the wider acceptance and long-term success of those projects. The research on participation in urban agriculture with VR and digital technologies is few and far between.

Building upon comparable methodologies in urban studies, Map Walk[1] has been developed by Tomkins, Viljoen and Bohn (2014) and used as a methodology to systematically yet informally facilitate community groups' participation process in gestation, promotion and consultation with a prospect to use the outcomes to influence policy- and decision-making processes for Urban Agriculture projects. As effective, easy-to-use, and user-friendly as this methodology is, it was felt that it can be complemented using additional means to capture emotional and cognitive responses using new technologies such as virtual reality (VR) interactive tours. A funded research project was therefore carried out to design and implement a VR-technology solution devised exclusively for this study as a complementary digital research instrument to investigate areas that are less likely to have been covered by the analog version of the research instrument (Urban Agriculture Map Walks). The prominence of VR in facilitation of

[1] Map Walk is a semi-structured guided tour using exclusively created orthographic maps of urban spaces with highlighted potential areas suitable for urban agriculture interventions, followed by a focus-group style meeting to discuss and document participants' views, opinions, and reflections on urban agriculture in the context specifics of the study cases.

participatory design which had been studied before (e.g. Piroozfar et al. (2022)) was one of, if not the most important capability that inspired the research team to choose the technology and develop a niche solution to best meet the intended aim and objectives of the project.

This project aims to investigate the role and impact of VR technologies in and the community stakeholder groups' perception of, and attitudes towards, the use of VR technology for urban agriculture community projects. To achieve this aim, following objectives have been pursued: 1) To critically review the latest research in the multi-disciplines involved in this research; 2) To learn the existing process of Urban Map Walks and its application to urban agriculture; 3) To develop an custom-built, customizable, easy-to-use, useful and flexible research instrument to facilitate co-participation; 4) To verify the instrument through user perception and attitudes towards the use of VR technology; 5) To establish areas for improvement; and (if possible): 6) To improve the VR experiment, rerun the user experience; 7) To highlight the contribution and lay the foundation for future research in this area.

Upon covering part of the in-depth literature review carried out for this study, this paper will explain the research design of the study including a brief overview of the development of the research instrument (which will be discussed in full detailed level in a separate paper), the data collection and analysis strategies, as well as the preliminary findings of the study with respect to development and improvement of the research instrument through Alpha and Beta Build stages. The full analysis of findings of the analog stage (map walk) and digital stages (Alpha and Beta Build) will be presented in separate publications later on.

2. Literature Review

2.1. Urban Agriculture

Agricultural activities moved to the city fringes and suburbia as a result of industrialization (Steel, 2013) and then back again to the urban areas when a revival of urban horticultural took place, predominantly in form of activities for food production (Appel and Spitthöver, 2011, Keshavarz et al., 2016). They have been used by the working class for an enhanced food security or the upper class as a place for self-realization, expression of individuality and a contemporary healthy lifestyle (Appel and Spitthöver, 2011).

It has been argued that although distinction can be drawn between urban agriculture and community gardens (and community food gardens as an extended concept), there could be benefits across the different concepts and that they have been used interchangeably (Tomkins, 2014). According to Kirby et al. (2021), food production in urban spaces can offer four potential categories of social benefits: health and wellbeing, economic opportunities, social cohesion, and education (Dubová and Macháč, 2019, Olivier and Heinecken, 2017, Reynolds and Cohen, 2016). As an environment "productive in economical, sociological and environmental terms", Continuous Productive Urban Landscapes (CPULs) have been proposed by Viljoen et al. (2005).

When first used by the UNDP in 1996 (Smit et al., 1996), urban agriculture was mainly concerned about the Global South – Africa, Asia and Latin America – but it has since prevailed in the United States (Balmer et al., 2005, McClintock, 2008), Canada (Kaethler, 2006), and the UK (Viljoen et al., 2005, Cullen, 2008, Tomkins, 2014) as well as other Global North economies such as Switzerland (Jahrl et al., 2021), Japan (Yuan et al., 2022), France and Germany (Kirby et al., 2021, Pölling et al., 2016) to name but a few. Kirby et al. (2021) studied differences in motivations and social impacts of urban agriculture types across case studies in Europe and the US. Political-administrative program (PAP) developed by Knoepfel et al. (2007) has been used for analysis of city policies to study the role of food gardening in addressing urban sustainability by Jahrl et al. (2021). Including social, health and well-being, disaster risk reduction, and environmental perspectives, Yuan et al. (2022) reviewed technological, socio-economic, and policy aspects of urban agriculture to highlight its value beyond mere profitability. Motivations for investing in allotment gardening have been scrutinized in the context of the city of Dublin by Kettle (2014). The role of community gardening has also been looked into for the purpose of place-making in social housing (Truong et al., 2022).

2.2. VR for Participatory Design

The Coronavirus pandemic exacerbated the move into virtual interaction environments (VIEs) which had already begun due to prevalence of game industry, wider availability of and accessibility to VR technologies and the proven benefits of VR in the AEC industry (Piroozfar et al., 2022). Cognitive mapping is essential for full spatial cognition (Briggs et al., 1973 in Walmsley et al., 1990) which can be characterized by three inter-connected features: "space itself, containing immovable structures and landmarks; objects within the space, which move or change state under certain conditions; and actors whose actions cause changes within the environment" (Dalgarno, 2002: p.154). MIT Nano Immersion Lab defines virtual reality as "a computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way". VR has been studied as a collaboration tool in children's design processes (Ryokai et al., 2022), for participatory evaluation of sound environments in urban spaces (Jiang et al., 2018), in experience design (Sherman and Craig, 2003), for participatory design experimentation with the elderly (Kopeć et al., 2019), as an interaction design tool in healthcare training (Matthews et al., 2020), to study novice designers' spatial cognition in collaborative design (Rahimian and Ibrahim, 2011), for semantic-based taxonomy in product design (Makris et al., 2012), in group debriefing in safety education (Luo et al., 2021), to investigate how immersion and interactivity drive VR learning (Petersen et al., 2022) and with reference to its effects in training simulators (Menin et al., 2022). A review of VR/AR (Augmented Reality) in human-robot collaboration (Dianatfar et al., 2021) classifies different areas of focus of publications in this area into: operator support, simulation, instruction (training) and manipulation (operation and control). However, apart from a comparative study of in-situ and VR walk-along interviews for auditing an urban park deck (Jaalama et al., 2022), there is very limited, if any other evidence, of previous work on participatory design for community projects, in general, and urban agriculture, in particular.

2.3. Map Walk Methodology for Urban Agriculture

A map walk methodology was exclusively developed to study food gardening and urban agriculture by Tomkins, Viljoen and Bohn (Tomkins, 2014) and used ever since by Tomkins in urban agriculture community projects. The methodology involves marking an urban area with spaces deemed suitable for urban agriculture, producing an illustrative map of the area, design a walk path, guide a group of voluntary participants study the map, visit the urban spaces and discuss the potentials of changing the use of the predetermined urban spaces to incorporate urban gardens. The group will then participate in a focus group discussion of their experience using the maps and their walking experience of the selected urban spaces. The results will be added to the maps and used to produce reports to feedback to decision making processes if and where applicable. Walkable MR (Mixed Reality) map has been used as an interaction interface for cultural heritage (Bekele, 2019). Geospatial information and AR have been combined in previous research in different cognate fields including urban planning and design (St-Aubin et al., 2010, St-Aubin et al., 2012), to combine walkable maps and orthoimages in museums and public spaces (Wüest and Nebiker, 2018), for training operators in urban utility infrastructure networks (Piroozfar et al., 2019a, Piroozfar et al., 2019b) and in urban history (Maiwald et al., 2019). There are no precedents of using VR technologies for urban agriculture community projects. We have developed a VR-based technology solution to supplement and potentially enhance the participants' physical map walk experience.

3. Research Design and Methodology

This research seeks to investigate different community stakeholder groups' perception of, and attitude towards, urban agriculture through VR. In order to measure the participants' attitudes and perceptions, multi-staged research with a qualitative methodology was designed. Prior to commencing these stages, and to help establish the knowledge gaps, shape the research design, and scaffold the findings of this study at later stages, a review of urban agriculture, VR for participatory design and 'map walk' methodology was carried out through secondary research. Upon establishing an existing knowledge-base, a series of primary research stages were conducted, developing on the previous stage.

These stages were divided into one analog site walk followed by two digital VR developments (alpha and beta builds) and their corresponding data collection/analysis processes. The researchers observed the participants in the analog stage - also referred to as the 'map walk' - and interrogated the data collected during this stage to be able to understand the nature and process of these urban agriculture studies and to subsequently assist in shaping the research instrument in the form of a VR application, through discussion and exploration.

The second stage of the study commenced with development of the alpha build of the VR application, followed by the second stage of data collection in the study (and the first for the digital stage). Following action research principles, this stage utilized a focus group method. This was achieved in 3 parts. The first part of this stage focused on presenting the VR application to the participants in several smaller working groups and giving them the opportunity to play with the developed VR application, whereby users could provide informal responses as they were observing the application. These responses allowed the researchers to shape the second part of this stage by validating/confirming these perspectives through further investigation. The second part of this stage consisted of a semi-structured interview, formed of a series of open-ended questions, maintaining a qualitative nature while addressing the experience presented to the participants in smaller working groups. A semi-structured interview was deemed suitable as it allowed the researchers to address the informal discussions made during the first part of this study, thereby providing a level of flexibility in the study while at the same time capturing specific concerns, needs and preferences of the members of each working group. Finally, in order to create a feedback loop among the participant groups, each cluster was brought back together in a larger group to participate in an open discussion amongst all the participants led by the researchers to highlight any key observations, concerns or opinions that other groups may have not highlighted in their individual clusters, reflect on other groups' feedback and conclude the data collection.

The findings of this stage were used to improve the VR application and develop the beta build. The beta build was then used for another round of focus group experiment. The methodology developed in alpha build and explained above, was replicated for the beta build of the VR application data collection through focus groups to allow for consistency and a level of comparability between the two stages (see Fig 1).

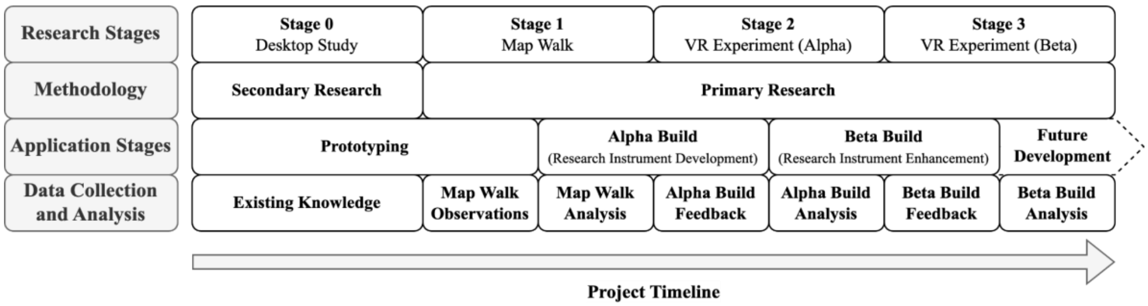


Fig 1: Research Design and Methodology

4. Preliminary VR Experiment Development

4. 1 Spawn in Place

The urban agriculture map walk is intended to provoke the imaginations of the participants, whereby individuals would utilize the map legend to understand what elements of urban agriculture could be placed in a given location. The users would then attempt to visualize these urban agriculture elements within the context of the location before discussing with their peers on elements such as its feasibility and sustainability.

Virtual Reality provides an additional dimension to the visualization of these urban agriculture elements, in which users would be able to place virtual objects in the scene as opposed to imagining their scale and proportions in context of the environment. In order to enable this visualization, a 'spawn in place' system was developed. This system allowed users to select an object from a UI (User Interface) menu before then placing the selected item onto the ground using a laser pointer.

4. 2 OpenStreetMap (OSM) Model

In order to provide context to the site, a 3D model of the city was desirable to include within the VR application. To facilitate the development of the 3D city, an open-source tool called 'Blender OSM' was utilized. This tool allowed the generation of 3D models within a given area; utilizing open-source data, elements such as building heights, building footprint, road paths, terrain levels and other geographical features were amalgamated to form a comprehensive 3D model within the modeling software Blender.

In order to efficiently represent the map generated by the research team, some edits were made to the generated model. The blender software aided in this as it provided the flexibility to edit any aspect of the imported data from the OSM plugin. In turn, the study area was highlighted in orange so that context could be derived from the surrounding buildings shown in white when viewed in context with the study map. This model was subsequently exported and imported into the game engine software.

4. 3 Drawing Tool

During the development of the application, participants highlighted the need to create their own placeable objects while also being able to manipulate existing site features. This, however, in practice, proved challenging due to time limitations and the extents that the UI provided for. To be able to address these queries, a drawing tool was implemented. Despite the different steer to what was set out, the drawing tool allowed users to draw in 3D space, be that written text or 3D objects, and be able to vision their imaginations more easily.

4. 4 Lighting and Baking

The urban agriculture walks are conducted at different times of the year at different times of the day to provoke a variety of responses to how the space might be used given the variance in climate and lighting. Therefore, it was important to capture how the scene may be lit within the VR application to communicate this variance to the user.

This was achieved by implementing an adjustable sun path that allowed the user to experience the site at different times of the day. The sun path followed real azimuth and altitude data at certain points in the day, and as the sun moved along this path, shadows and general scene lighting was updated. This meant that the user could understand which areas of the site would have more or less sun than others, allowing them to make informed decisions about where they might place the objects they are spawning into the scene.

4. 5 Audio

The use of audio was necessary in order to convey ambience, effect, and information to the user in order to improve their immersive experience. Towards this, a multisensory approach can be taken to use as many senses as possible (kinetic, visual, auditory). A variety of audio experiences can be created by combining interactive and adaptive audio techniques. Both diegetic sounds - which are heard as part of the environment such as dialogue, sound effects, and background noise - and non-diegetic sounds - that are related to the application menus and not part of the 3D world - such as feedback and user interfaces were used to help improve the user experience; the former to improve the sense of immersion and the latter to deliver or emphasize on the (background) information.

4. 6 LiDAR

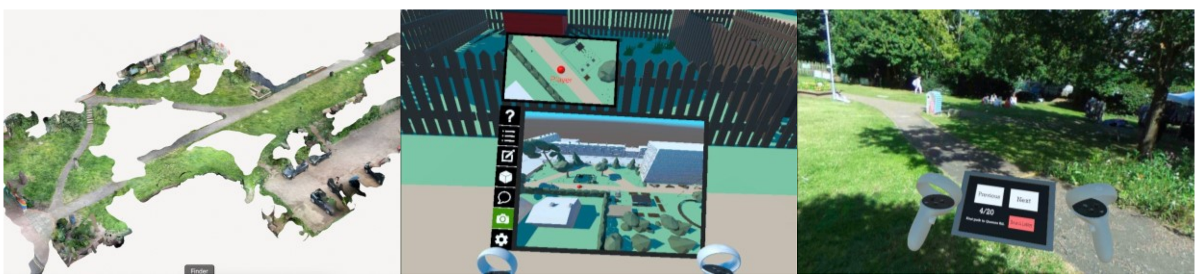
LiDAR was used as an approach to scanning and accurately digitally recreating the urban agriculture site. Although not as accurate as laser scanning stations, this technological approach was chosen to avoid risk of damage to expensive equipment exposed in public spaces. Furthermore, large file sizes from the high-fidelity output of laser scanning would not be necessary for this use case.

4. 7 Minimap

Taking from gaming principles and jargon, a minimap - a small map that displays an aerial view, giving an idea of location of the user in the environment, while also identifying points of interest - would serve this purpose.

4. 8 360 Photograph Walkthrough

The application incorporated 360-degree images into a 'walkthrough' format as a supplement to the physical walkthroughs, and complimented the annotated scale models of the site as contextual information. By using photos, context could be provided as to the existing urban agriculture site and more intricacies can be displayed than that of a digitally recreated VIE (e.g., due to hardware limitations, etc.). Furthermore, they provide a comparison between the existing and proposed uses of the site. Through the virtual experience, limitations and requirements associated with physical presence could be overcome (location, accessibility, mobility, weather and time, cost).



Figures 2: a) LIDAR Scan; b) Minimap and Overview Camera; c) 360 Photos used in application.

4. 9 Locomotion and Scene Transitions

A locomotion system in VR was required to enable users to move around the 3D environment to provide them with a seamless, intuitive, and immersive way to move within VIEs, and furthermore limit discomfort and sense of encumberment. In addition to the locomotion controls, a method for loading Unity scenes was required to enable user transition between them via U.I. control or through a 'portal', such as an interactive item within the scene itself (e.g. a door).

4. 10 Modeling and UV Mapping

Modelling of 3D objects was a necessary undertaking of constructing and forming the static (close, surrounding, or distant environment) and interactive elements (such as spawnable objects and other dynamic objects) within a given scene. In order to create a more aesthetically pleasing, immersive and believable environment for the users, care and attention was required during the modeling process to ensure correct detail, scale and texture of each object.

UV mapping techniques were involved as part of the modeling process, so that 3D objects could be clad with texture maps in order to appear more natural and realistic. This process is carried out in 3D software such as Blender.

4. 11 User Interface

A well designed User Interface (or U.I) was required to provide a graphical representation of elements allowing the user to interact with the application, serving as a bridge between user and software to input information, receive feedback, and access the features and functionality of the software.

The aim for the UI design was that it be intuitive and aesthetically pleasing, resulting in tasks being performed efficiently and effectively. This comprises overall design, layout, and organization of the UI which has an impact on the user experience, and should be designed in a way that is both aesthetically pleasing and functional.

5. Data Collection and Analysis

5. 1 Urban Agriculture Study Site

Prior to developing the application, geometric and contextual data was captured from the site of interest. This was achieved using a mix of 360 photographs, LIDAR scanning and open source mapping data. The LIDAR scan was achieved using the application 'Polycam' on an iPhone 13 Pro, whereby the development team walked around the perimeter of the site, capturing the bounds of the contextual geometry. This geometry provided a base measurement for the 3D model to be developed from, allowing accurate proportions to be reflected in 3D.

The 360 photographs, intended as reference images for the development of the 3D model, were subsequently used in the final build acting as a 'site walkthrough' for those unable to visit the site. These photographs were captured using a GoPro Max and Ricoh Theta 360, both of which utilized tripods set at eye level to reflect what the participants would visualize were they at the site.

Open Source mapping data was utilized later during the development stages as a means of capturing the cityscape. Data from 'open street map' was imported and 3D generated in Blender using the 'Blender OSM' plugin. This was then used comparatively with the LiDAR scans to generate an accurate site perimeter while maintaining an effective cityscape backdrop.

5. 2 Experiment

Following the development of the application, the VR study went on to present the software program to a group of participants. The presentation for both of the feedback stages was set up in the same fashion. The room where the experiment took place consisted of up to eight 'stations' consisting of a VR headset casting to a screen at the end of a table; participants could sit around the table and see the VR users' perspective cast onto the screen. The VR headset utilized for this experiment was an Oculus Quest 2, opted for due to its wide use case, ease of use, availability and untethered nature.

Each table consisted of up to 4 participants with 1 presenter. Participants took turns using the application for up to 5 minutes, while informally discussing aspects about the application with one another. Subsequently, the groups took a short break before returning to respond to a series of questions prompted by the presenter. The questions poised to the user groups focused on elements surmounting to Virtual Reality, Urban Agriculture and User Experience. Succeeding this, each of the tables combined into one large focus group to share their individual discussions and help highlight any potential conflicting or corresponding arguments poised by each table.

Figures 3: a) Researcher explaining controls; b) Participants using application; c) Group discussion

The feedback obtained by the users in these sessions was collected using audio recorders and note-taking. This data aided in the subsequent development stages wherein the software could be adjusted to align more closely to the comments provided by the participants.

5. 3 Data Analysis
The data collected at each of the respective feedback stages was categorized into two distinctive areas; feedback pertaining to the topic of Urban Agriculture and feedback on the VR application itself. Comments relating to the VR application were prioritized in order of importance, higher priority items being those that would cause significant disruption to the user's experience. In addition, any items that were insurmountable during the project time period, were detailed and excluded from the development stage, highlighted as areas to be addressed for future development of the application.

Data pertaining to the topic of urban agriculture was comparatively assessed against its frequency of occurrence during the focus group conversations. Those topics that occurred more frequently in discussion were prioritized as areas to address/develop tools for in subsequent builds of the application. Similarly, those that were discussed infrequently were noted and excluded from development. Upon creating a priority list, the development team divided the tasks and proceeded to add features and correct any application errors/bugs.

6. Concluding Comments and Future Research

In this paper, the design and preliminary findings of this research in this two-part study have been presented; those were used to inform the later development of a VR-based system providing a digital supplement to an analog methodology for urban agriculture to help community stakeholders experience new dimensions which are not otherwise accessible merely through the analog methodology. In combination with the findings of the analog map walks, prior literature was drawn upon to define the parameters of, and approaches to, the experiment, identifying the elements and factors that should be incorporated into the design of such a VR-technology solution.

The use of VR in developing the digital walkthroughs demonstrated not only how it complimented the traditional approach but highlighted several benefits over the analog map walks including: a more immersive experience for the participants, enhanced comprehension of the subject matter leading to improved outcomes, enabling accessibility, as well as promoting proactive user participation in the design process of associated community projects. Furthermore, it showed promise for use in aiding decision-making in community projects. User participation was set up to give users the freedom to choose how they engage with the application and to provide constructive feedback in order to maximize potential insights that could guide future development.

Given the unique requirements of the project, a tailored approach to application development was deemed necessary in order to unlock the full potential of the technology. This approach was more resource-intensive than simply relying on pre-defined solutions. However, the ability to include niche features made it the most suitable option as it was not bound to limitations - in terms of assets, software and/or hardware compatibility/interoperability - inherent in an “off-the-shelf” application. As such, Unity game engine was employed to build the application, and all other pre-existing software packages which were reviewed and tested were disregarded.

Besides the typical project challenges, namely short timeframe, limited resources (including hardware and finances), and complexity due to the tailored approach, the majority of issues encountered were related to programming bugs, glitches, or optimization issues within the game engine editor. Additionally, there were some minor issues with software-to-software and software-to-hardware interoperability, which, for the sake of brevity, will not be discussed in this paper.

This paper contributes to research in the field through exploring a unique and niche use of VR, including its capabilities and limitations, tailored towards use as a tool to facilitate participatory design with a specific focus on community projects in general and urban agriculture in particular. This adds to existing knowledge in the field which is currently few and far between. This research not only serves to promote and further establish 'Map Walks' as a methodology, but also aims to showcase the additional features that can only be enabled via VR-technology enabled interaction with existing settings and add, omit or amend desirable features or elements of urban agriculture to an existing urban space, explore, evaluate, and document alternative options and collect feedback from a wider range of community participants. This feature is what has effectively supplemented the existing map walk methodology.

Furthermore, this research provides scope for future research to explore greater complexity of features, including those that facilitate more advanced collection and storage of data digitally and to the cloud, as well as those that add to the depth and quality of user experience. Additionally, the potential of Augmented Reality (AR) as an alternative digital medium was considered and has promises to be explored, with future research comparing the effectiveness of both VR and AR for use in user feedback-led development of community projects, taking into consideration metrics such as capturing emotional and cognitive responses, as well as gauging ease of use and the level of user comprehension and engagement. The application of VR to garden design could also be extended into the design of public urban spaces. The expansion of VR (and also AR) for niche social applications is an area for further investigation to help enable people to contribute to participatory design processes (similar to garden/urban walks, museum virtual exhibitions, etc.) with an aim to encourage and/or facilitate the inclusion of disabled, less-abled and neurodiverse individuals' participation in society.

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Scientometric Analysis and Machine Learning as Tools for Predicting Construction Equipment's Economical Factors

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Abstract

This study is based on previous research about estimating the residual market value (RMV) of excavators, using machine learning (ML) techniques. Boosted by the promising results of the initial study, the current one seeks to expand the prediction algorithm on different types of earthworks equipment, also by enriching the equipment's database. The conducted scientometric analysis revealed the remaining untapped knowledge concerning ownership, operation and maintenance cost data, that is still been gathered by the global construction equipment (CE) manufacturers, owners or dealers. The current study attempts to highlight the perspectives that machine learning offers, when coming to predict several economic factors from the utilization of different types of CE. The equipment's RMVs were collected from global equipment resellers and auctions. The prediction model was developed by using RapidMiner Studio software, while the scientometric analysis was performed using VosViewer software. The ultimate goal of this approach was to develop a user-friendly platform, supported by RapidMiner Studio, to predict RMVs through certain values, which represent the equipment's financial and operating condition. The algorithm concluded that for any CE, the most dominant factor for predicting its residual market value is its initial purchase.

Keywords

Construction equipment, machine learning, residual market value, prediction, scientometric analysis

1. Introduction

A scientometric analysis was initially performed, with a view to investigate research gaps, scientific trends and interrelationships between the most common used scientific terms.

According to Vorster (2009) [1], the RMV of a machine when sold at any point in its life is an unknown that depends on many factors. Previous multidiscipline studies resulted that one of the most unstable, fluctuating but dominant factor, is the market itself. For this is the reason a machine might have different residual values in different years depending on many factors with the most dominant one that of the construction output of the year under search. If, for example, there is a high demand for a specific model then its residual value is high, whereas for the same model one year before its market value might have been less due to low market interest. To comprehensively cover a wider range of CE types, this study collects the resale and auction prizes of 1000 excavators, 1000 loaders and 977 dozers from Caterpillar. Their manufacturing year ranged between 1980 and 2020. A representation of those equipment data is depicted on Table 1.

Table 1. CEs Values Range

	CE Type	Hours of use	Manufacturing Year	Residual Market Value (€)
1	Excavator	0 – 63.788	2001 - 2020	104 – 914.112
2	Dozer	10 – 275.226	1981 - 2020	20.393 – 1.252.233
3	Loader	8 – 12.6045	1980 - 2020	14.855 – 1.202.365

The equipment data were sourced from the most popular internet sites for sales and auctions, such as constructionequipmentguide.com, euroauctions.com, machinerytrader.com and catused.cat.com. Equipment records concerned the global market for the 1st quarter of year 2021. Those records were collected and classified according to their type, size, manufacturing year, country of reselling (equals the country of purchasing), effective hours (hours of use – reflecting the condition of the machine) and their current RMV, resulting a database consisted of almost 1000 records for each equipment type.

This study attempts to move one step further, by calculating the initial purchase price of those equipment, with the assumption that the year of purchase equals the manufacturing year. For this conversion, equation (1) was applied.

$$Present\ Value = \frac{Future\ Value}{(1+i)^n} \qquad (1)$$

where:
i = the interest bank rate of the country in which the equipment was purchased
n = period of time

The interest rate of each country for every specific year of purchase was extracted by the World Bank's website (www.data.worldbank.org).

Several publications were studied, to reveal the relations between ML and CE financial management, as shown in Table 1. ML was implemented using RapidMiner Studio software. Among various ML capabilities, RapidMiner offers the Auto Modelling ability, where the user provides the necessary data and defines the prediction attribute. The main goal of this study is to identify the patterns under which the CEs' RMVs are evolving, under demanding market rules, and to present robust estimations of RMVs.

Table 3. Previous studies on ML application for RMV estimation

Authors	Year	Title	Contribution
Bertoni et al. [6]	2017	Mining Data to Design Value a Demonstrator in Early Design	They applied data mining algorithms on a dataset build on a wheel loader's performance and contextual and environmental data. They focused their estimation on the fuel consumption of alternative design concepts and estimated the performance variations given different contextual variable.
Fan and Jin [7]	2011	A study on the factors affecting the economic life of heavy construction equipment	They managed to extract rules leading to different cost patterns and therefore different economic life spans of heavy equipment, more effective maintenance strategies and to an accurate comparison among the equipment cost performance from various classes, makes and amount of service during their life cycle.
Spinelli et al. [8]	2011	Annual use, economic life and residual value of cut-to-length harvesting machines	They gathered a large database of second-hand machine sale offers and conducted a statistical analysis. They concluded that the equipment's residual value is strongly related to machine age.
Fan et al. [9]	2008	Assessing Residual Value of Heavy Construction Equipment Using Predictive Data Mining Model	Stressed the importance of predicting the residual value of heavy construction equipment to an acceptable level of accuracy, to maximize the return of this investment. They introduced a data mining-based approach for estimating the residual value of heavy construction equipment.
Lucko et al. [10]	2006	Statistical Considerations for Predicting Residual Value of Heavy Equipment	Identified the factors that affect the residual value of a construction equipment, and they examined them comprehensively by analyzing real market data from equipment auctions, about track dozers.
Lucko [11]	2003	A Statistical Analysis and Model of the Residual Value of Different Types of Heavy Construction Equipment	Through multiple linear regression analysis, he performed a residual value prediction, by using auction sales data and heavy construction equipment manufacturers' publications.

Michell [12]	1998	A Statistical Analysis of Construction Equipment Repair Costs Using Field Data & The Cumulative Cost Model	By using field data on 270 heavy construction machines, he identified a regression model that can adequately represent repair costs in terms of machine age in cumulative hours of use.

2. Methods

2.1 Scientometric Analysis

This study attempts to reveal the void regarding the researched topic, by applying a scientometric analysis, to objectively map the scientific knowledge on this specific field and to identify the research themes and the corresponding challenges based on the scientometric results, with the use of the VosViewer application [2], developed by Van Eck & Waltman (2010) [3]. A four-step process was utilized, to create those scientometric maps, as shown in Figure 1.

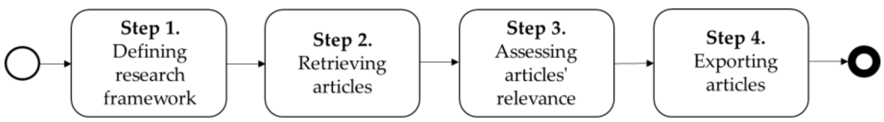

Fig. 1. VosViewer’s map creation flowchart

In step one, the research framework is defined, with the scope to identify and set the desired goals. It includes an initial investigation, to separate the relevant from the irrelevant research components. Step two includes the retrieve of the close related articles with the examined topic. Those articles were extracted by Web of Science and Scopus, covering a period from 2001 to 2021, by using the search terms of Table 1. Step three includes the relevance assessment of the extracted publications, to finalize those that are going to be inserted for scientometric mapping into VosViewer. 192 articles were exported for the scientometric analysis.

Table 1. Search Terms Boolean Operators

Boolean operator	Terms	Description
	construction equipment	The term that describes the main topic and the core search rule
OR	equipment	Used for searching all machinery and equipment-based
OR	machinery	publications, in order to exclude the irrelevant
AND	residual market value	Term that specifies the distinctive topic, concerning residual market value
OR	rmv	The abbreviation of residual market value
OR	residual value	Term that specifies an alternative term of residual market value
OR	rv	The abbreviation of residual value
OR	owner*	Term that specifies the distinctive topic, concerning owner, ownership, etc.
OR	cost*	Term that specifies the distinctive topic, concerning cost
AND	engineer*	Term that determines the desired scientific domain
AND	machine learning	Specifies the predicting artificial intelligence method
OR	artificial intelligence	
OR	estimate	Used for searching alternative terms for machine learning
OR	predict*	

Figure 2 presents a significant increase after 2018 for publications and citations covering topics related with the search terms of this study. It signifies the increased scientific interest, following the trend of machine learning integration into many different aspects of the construction industry.

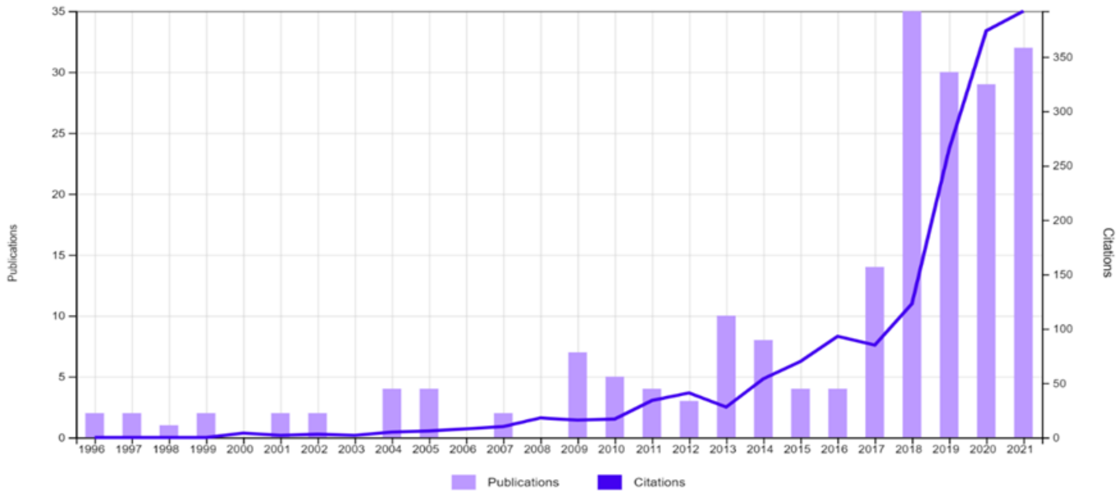

Fig. 2. Total Number of Publications and Citations

The fourth step includes the extraction of the found articles, to be processed by VosViewer. The final product is a comprehensive network comprised by coexisting terms inside the overall publication cluster, where their linkage strength, their occurrences, and their relativity are visible, weighted, and clustered. Every cluster receives a different color, and each color designates a specific research area. The terms inside each cluster are represented by circles, and their size reflects the number of publications in which they were found. The spacing between those circles indicates their relatedness, and their degree of relativity is indicated by the thickness of the curved lines connecting them. The degrees of relatedness between words are indicated by the curved lines [4]. The produced clusters by subject are shown on Table 2, and the keyword co-occurrence network is visualized in Figure 3.

Table 2. Keyword Co-occurrence Clustering

Cluster Number	Main Subject	Color	Terms Included
1	Cost	Red	9
2	Effective hours of use	Green	8
3	Strategy	Blue	8
4	Management	Yellow	7
5	Construction Equipment	Purple	6
6	Useful Life	Light blue	6

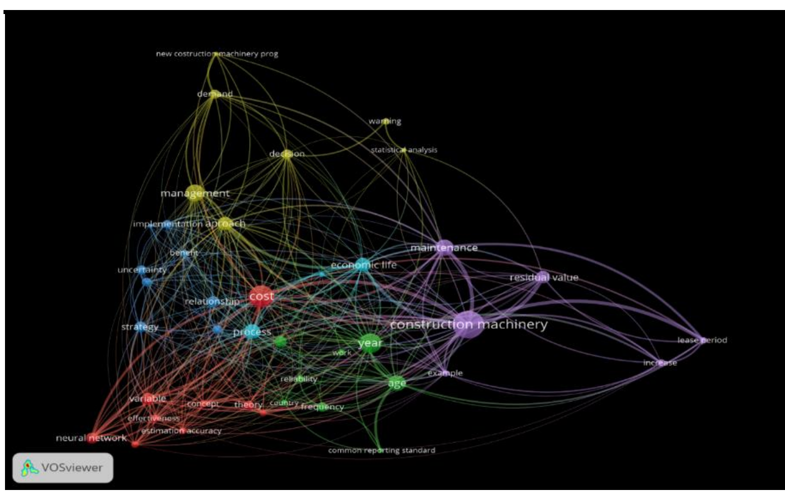

Fig. 3. VosViewer map based on keywords (network visualization)

The analysis based on keywords indicates that the network is constituted by strong links between the terms of "construction machinery", "maintenance", "residual value", "economic life", "cost", "management" and "neural network", even though they belong to different clustering groups. Nevertheless, the "Cost" cluster (red) is located near the "Useful life" cluster (light blue). Specifically, the term "cost" has been putted separately from the rest of the red group, but in a centric position, in order to be closer with the rest of the clusters, indicating their strong relationship. But the most important issue of the network's analysis is the fact that the "machine learning" term is not visible at all. Even the appearance of the "neural network" term, as a ML method, is not considered significantly close (although the thick curved lines indicate a strong term co-occurrence) with the rest of the terms to be able to justify a strong utilization of ML for CE residual value estimation. Thus, its location justifies a "knowledge gap" between ML and the rest of the clusters, a fact that provides a uniqueness to the current study.

2.2 Machine Learning Model

The CE's RMV fluctuation was performed using a machine learning model. This model was developed with RapidMiner Studio software that provides the Auto Modelling ability, which offers sufficient capabilities to accelerate the ML process and analyze the results. It develops different types of ML models, depending on the imported data type, allowing the user to select the most efficient one and proceed to further analysis [5]. The constructed database includes eight distinctive attributes with records from each equipment: a. CE type, b. Effective hours (hours of use), c. Manufacturing year, d. Country of purchase, e. Residual Market Value, f. Interest Rate (by the year and country of purchase) and, g. Purchase Initial Value (PIV). PIV was calculated by applying equation (1) transformed in equation (2).

$$PIV = RMV \times (1 + i)^{(2021 - Year\ of\ manufacture)} \quad (2)$$

RapidMiner evaluates the imported database for its quality, characteristics, and diversity of the data. It also presents an analysis for which of the data are suitable to be exploited for ML and prediction and which are not. It uses specific quality indicators for the data evaluation: a. Correlation, for data categories very close to the prediction goal or for those that are irrelevant, b. ID-ness, for attributes that all their data are completely different, c. Stability, for attributes that have a great percentage of the same data or values and d. Missing, for data categories with absence of values. At the final stage, the software proposes several prediction models. The user can compare the performance of each model and decide which is the best, depending on the relative error, the standard deviation and the training time.

The imported database can be processed by three types of ML: prediction, clustering and finding outliers. This study focuses on RMV prediction. The machine learning techniques used by RapidMiner are: a. Generalized linear model, b. Decision tree analysis, c. Deep learning, d. Random forest, e. Gradient Boosting trees and f. Support vector machine. Overall, one of the main advantages of all the machine learning tools is that these models lead to an effective visual analysis, since are similar to that of a human's neural network, and thus they can process unorganized data [6].

The results for each type of CE are presented on a table form summary (Table 4) and the best method is been proposed, according to the best performance (due to the minimum correlation), the minimum scoring type and the minimum total time (scoring + training), for each of the five types of error: a. for the Mean Squared Error (MSE), a risk function and a measure of the estimator's quality, which measures the average of the squares of the errors, that is, the average squared difference between the estimated and the actual value, b. for the Root Mean Squared Error (the root of MSE), which is a measure of accuracy, to aggregate the magnitudes of the errors in predictions for various times into a single measure of predictive power, by comparing forecasting errors of different models for a particular dataset, c. for the Absolute Error, which sums up the absolute values of the differences between labels and predictions and divides this sum by the number of examples, d. for the Relative Error, which is the average of the absolute deviation (error) of the prediction from the actual value divided by the actual value, and e. for the Correlation, which describes the strength of relationship between two numeric attributes in a data set and also the direction of this relationship (positive, negative or none). The bold values in Table 4 represent the proposed ML model with the best performance (minimum error) for each type of CE.

Table 4. Error comparisons

Model	CE Type	Root Mean Squared Error	Absolute Error	Relative Error	Mean Squared Error	Correlation
	Dozers	56.531,416	38.772,172	18%	3.320.836.660,315	0,947

Generalized Linear Model	Loaders	31.975,959	11.718,0	7,55%	1.447.867.413,916	0,969
	Excavators	**7.084,824**	7.457,271	**4,3%**	**52.353.904**	0,997
Deep Learning	Dozers	**34.293,262**	19.153,017	11,2%	**1.266.307.185,587**	**0,984**
	Loaders	25.457,175	12.753,6	7,3%	710.876.496,955	0,982
	Excavators	12.496,611	**3.872,302**	8,6%	181.146.105	0,996
Decision Tree	Dozers	35.964,155	**15.164,809**	**6,3%**	1.529.876.859,582	0,978
	Loaders	19.833,866	8.134,19	3,4%	528.486.793,713	0,983
	Excavators	20.937,937	7.216,24	4,5%	481.976.300	**0,998**
Random Forest	Dozers	41.611,137	19.723,803	8,2%	1.926.634.217,607	0,978
	Loaders	**10.693,513**	**4.584,70**	**3,4%**	**182.614.092,579**	**0,997**
	Excavators	21.023,473	9.149,153	6,9%	483.738.082	0,989
Gradient Boosted Trees	Dozers	47.663,163	17.708,397	6,9%	2.606.364.645,869	0,957
	Loaders	27.674,42	9.970,41	4,7%	977.796.280,210	0,967
	Excavators	17.062,412	6.673,099	5,2%	338.436.652	0,992
Support Vector Machine	Dozers	155.200,944	96.717,353	32,8%	24.513.375.194,25	0,708
	Loaders	85.182,299	44.436,5	20,2%	7.897.000.448,640	0,58
	Excavators	105.446,357	53.850,22	28,1%	11.506.444.351	0,557

3. Results

Further analysis of Table 4 reveals the best ML method for predicting the RMV of each CE. So, when coming to dozers, Deep Learning appears to have the best performance, since this ML method present the less errors. For loaders, Random Forest performed better than any other method and for excavators, the Generalized Linear Model was dominant.

After every prediction, RapidMiner provides also a weighting table for each attribute, as shown in Table 5, where, for every CE, the purchase – initial value was the most crucial factor, when coming to predict their RMV.

Table 5. Attribute Weighting

Attribute	Weight		
	Dozers	**Loaders**	**Excavators**
Purchase – Initial Value	**0.871**	**0.867**	**0.885**
Manufacturing Year	0.204	0.180	0.157
Country	0.084	0.058	0.053
Effective Hours	0.082	0.039	0.031
Type	0.016	0.029	0.019
Country's Interest Rate	0	0	0.003

For the purpose of this study the simulation ability of RapidMiner was also utilized, to identify the accuracy of the ML model and if the predicting results are reflecting the market reality. In the selected example the user can choose between different types of Caterpillar loaders, eg. Cat 980M Wheel Loader and insert the depicted in Figure 4 parameters. In this way he will be able to know how much he should sell the equipment after five years of use, with 4.231 operating hours and with an initial purchase price of 313.932€, according to the market rules. The algorithm predicts that he should sell the equipment for the price of 278.127€, which is close with the average price of 265.000€ in the selling market of 2021. In the same way, the user who just purchased a CE could also predict its residual market value after a certain number of years and with certain operating hours.

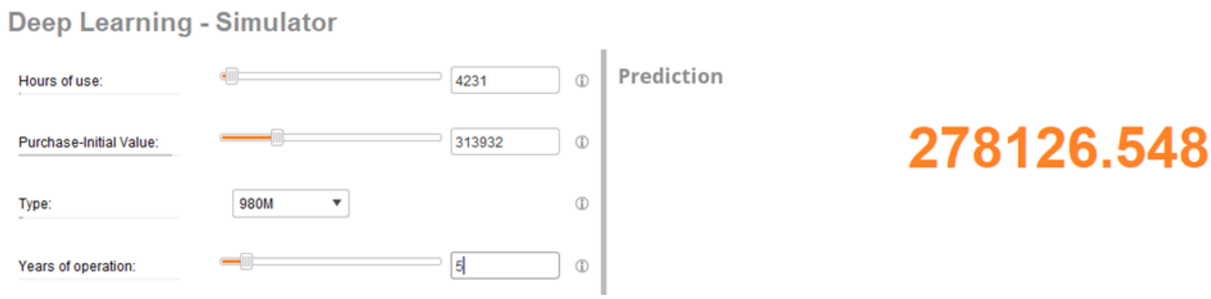

Fig. 4. RMV Prediction Simulator

4. Discussion

The idea of utilizing ML methods to estimate CE's economic indicators was a challenge worth to be considered also by previous studies, but they were only examining the prediction problem from the statistical perspective or by applying specific ML methods. However, no research has been found to systematically summarize different ML methods and provide the chance to select the one that best performs. Furthermore, this study dives deeper into the ML possibilities, to develop a software assisted simulation tool for predicting the CE's RMV, taking into account strict market rules. Moreover, this analysis is based on the assumption that all the machines are maintained adequately accordingly the manufacturers' manuals depending on hours worked and site conditions.

The practical applications of this study principally relate to helping respecting stakeholders to better understand the importance of predicting CE's economic factors. More specifically, it offers valuable indicators to: (i) monitor the RMV evolution of any kind of equipment, (ii) reinforce their financial management, iii) predict certain financial indicators and (iv) thus ensure the most efficient and reliable return of investment.

5. Conclusions

Construction equipment represents a significant capital investment for its owner. Thus, its management strategy, which includes monitoring every financial parameter during his operating life, offers the opportunity to gain most of this resource. This study was challenged to exploit the scientific gap concerning the examined topic, in order to offer a user-friendly and accessible method to monitor and predict the residual market value of three different kinds of equipment. Assisted by VosViewer software, the conducted scientometric analysis offered the opportunity to identify scientific trends and gaps, but also to examine the interrelationships between multidisciplinary domains, with the scope to understand the way the CE market evolves and behaves.

This study presents an innovative approach on predicting the RMV of different types of construction equipment, by using advanced ML techniques, through RapidMiner software. The equipment initial purchase value was the most important factor that determined its RMV. This result supports the idea that to ensure a successful financial strategy, the purchasing price should be taken under serious consideration. It signifies the need for applying a predefined and well-planned construction equipment replacement strategy, taking into account current or future market and auction trends.

RapidMiner analyzed a database consisted by 1000 excavators, 1000 loaders and 977 dozers from Caterpillar, trained the ML model, and presented interesting fluctuations of their RMV. This huge data enables more secure predictions if treated well. The software processed six different ML methods and proposed the most efficient ML method for each equipment: i) Deep Learning for dozers, ii) Random Forest for loaders, and iii) the Generalized Linear Model for excavators. For some equipment the model presented great differences between the predicted and the current RMV, mainly because the current RMV is not a mathematically calculated value, but it is determined by the market itself and the law of supply and demand, confirming that the economic situation of the country and the indexes of construction output play a significant role in determining market's trends.

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Drivers of Information Communication Technologies Adoption in the South African Construction Organisations

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Abstract

The building sector relies entirely on good communication among teams, individuals, and organisations. But communication in a project-based environment involves different stakeholders and individuals that come together for a certain period to share the project's goals as well as organisational goals. The adoption of information and communication technologies (ICTs) has developed a productive and active method of information exchange among experts. This study set out to evaluate the drivers of ICTs in South African construction organisations to encourage more adoption. An e-questionnaire was employed as part of a quantitative research technique to gather information from construction industry professionals. They consist of mechanical, industrial, and electrical engineers, construction managers, and project managers, as well as quantity surveyors. Standard deviation (SD), mean item score (MIS), and Kruskal-walli's were utilised to examine the collected data. The results showed that the most prominent drivers of ICTs in construction organisations involve the elimination of time-consuming processes, communication and collaboration, and maximized project profitability. It is recommended that construction professionals should adopt the various ICTs because of the advantages they bring to construction projects from inception to completion. Additionally, training should be given to all the project members to encourage its adoption.

Keywords

ICT, Communication, Construction Industry, South Africa

1. Introduction

Projects in the construction industry are large, and complex involving many stakeholders, and requiring continuous communication of a large amount of data during the construction phase of project execution (Zhang and Yuan, 2016). According to Cheng et al. (2001), communication is defined as the transferring of data from one individual to another or among a group of people which can be done in writing or verbally. These data usually incorporate operation dates, skills, technology, and knowledge. Adan et al., (2012) asserted that communication is a construction key factor that should be done honestly, openly, and efficiently to promote the execution of a construction project's success. In general, communications represent the foundation on which stakeholders build their relationships with clients and other project stakeholders (Cheung, 2013). The building sector relies entirely on good communication among teams, individuals, and organisations. Putnam & Nicotera (2009) stated that ICT tools enable effective communication among organisations and stakeholders in the construction industry. In addition, the assembly and accumulation of works on a vast scale are necessary for the building project's execution, for it to be realized. Therefore, effective planning which is made possible by ICT is necessary for a project to succeed in any construction company. According to Dawood (2010), stakeholders have historically communicated project data mostly through paper documents such as architectural drawings, specifications, engineering, bills of quantities, and schedules of materials. Sheglabo (2016) backed up this claim by stating that this paperwork often requires recurrence and constant information changes when transferring and recording data from one media to another, which could result in data mistakes and in some cases, data loss. The development of information communication technology (ICT) has therefore enabled digital communication between different members of the industry to be possible, and enhanced an active and proficient way of exchanging and storing data with negligible or no mistakes (Ahuja, 2010). Weber and Kauffman (2011) stressed that the worldwide, global adoption of information and communication technologies (ICT) presents information systems (IS) and electronic commerce academics with unique opportunities to conduct research that will have a positive impact. The adoption of and expenditure on ICTs are mainly driven by sectors such as insurance, information, finance, manufacturing, scientific, professional, health care, and technical services (Weber and Kauffman, 2011). ICT is also employed in several building industries, as explained by Hu & Kapucu (2016), to foster strong working relationships and cooperation between individuals and organizations. ICTs is also employed in the business for worker learning platforms, training sessions, and experience sharing. However, despite their potential contributions, and technical advancements in the construction industry; the construction industry has lagged in the adoption, compared to other industries. This shows that the construction sector is missing on a lot of business advantages including fast communication, and cost effectiveness (Tanga et al., 2021a). Therefore, this research aims to investigate the drivers of ICT in the South African construction industry.

2. Reviewed literature on construction ICTs

Adriaanse et al., (2010) stressed that ICT usage is influenced by the advantages and disadvantages of ICT applications as well as the skills and knowledge required for ICT use. The disadvantage is that the use of ICT can affect the conventional forms of the organizational procedures within the building industry and result in a modification in organizational procedures and activity, working strategies, and culture according to Ibironke, et al. (2011). Hu and Kapucu (2016) highlighted a few benefits of ICT basics to project execution in the construction sector which include decreasing the time for information handling, communicating data and upgrading the exchange for viable and successful decision-making and masterminding among building members, and enhancing building efficiency. The professionals and other parties involved in projects have benefited greatly from the introduction of ICT to the building sector (Tanga et al., 2021a). Mohandes and Omrany (2015) opined that ICTs such as building information modelling (BIM) which is a collaborative tool that allows the planning, building, and design of a structure within a single 3Dmodel is beneficial. Besides BIM, Augmented and virtual reality (AR and VR) are also part of ICTs. These are tools utilized for project data exchange, labourer's education and visualization, time management, and programme safety (Ahmed, 2018). Sensors which are small sized devices equipped with sub-systems communication, and resource processing cannot be excluded from relevant ICT tools in recent times (Ammari, 2018). Additionally, the internet of things (IoT), representing a system of interrelated devices connected to the internet according to established protocols via information sensing equipment are also included in ICT tools (Patel et al., 2016). Also included is enterprise resource planning (ERP), one of the significant ICT tools which consists of interconnected groups of comprehensive software that can be used to oversee and integrate all of the business procedures such as project management, accounting, risk management and compliance, and procurement within a company (Shehab et al., 2004). The main benefits of using ICTs include the expansion of the work done, financial control, better information interchange, less complicated and quicker access to information, and a reduction in errors while identifying unrecognized problems in numerous tasks. Additionally, ICTs benefits for the building sector also include providing the best possibility for information processing and shortening the time for data transmission (Tanga et al., 2021a). As indicated by Ibironke et al., (2011), it is one of the two main considerations that have affected the building sector over the the past couple of years when there was an expansion in computer possession by building experts, which was related to the accessibility of the software packages. IT turned out to be progressively important in dealing with a vast volume of data and in overseeing complex projects (Ahuja et al., 2009). It is a field that offers numerous potential advantages and chances to the building sector in general, and to the professionals specifically. It is also important to note that the adoption of ICT is a business strategic decision/direction and true front end strategic planning (FEP) drives the adoption (Govender, 2013). Burger et al., (2018) summed up the effect of ICT in building as the expanded speed of conveyance and work execution, upgraded quality, and arrangement of the large scope of administration services. The drivers of ICTs adoption involve:

2. 1 Increased Profit and Maximized Project Profitability

In the 21st century, ICT's usefulness to many fields of human endeavour including construction activities cannot be undermined because it has contributed immensely to the success of day-to-day businesses (Govender & Pretoruis, 2015). Apulu & Latham (2011) and Tanga et al. (2021a) explained that the use of ICTs has allowed organisational expansion through improved performance which is made possible through fluent and rapid information transfer amongst project parties. Furthermore, ICTs will also help to strategies data that is required to obtain sales targets leading to increased profit (Apulu & Latham, 2011; Tanga et al., 2021a). Therefore, the more profitable ICT is; the more companies are motivated to employ it in their operations. According to Tanga et al. (2022) and Tanga et al. (2021b), ICTs allows data management for easy organisational work and data flows, sound business decisions based on the available data, leading to the organizations having a competitive advantage over rival companies, as well as a maximised project profitability.

2. 2 Speed and Customer Satisfaction Results

Kannabiran & Dharmalingam (2012) stated that ICTs are everyday modern tools that help to move from manual to an electronic data processing to promote productivity. The productivity of construction works and projects is recognised as one of the reasons explaining ICT usage in organisations (Tanga et al., 2021a). Apulu & Latham (2011) opined that most industries chose to embrace ICT to become increasingly effective in their different business operations in terms of speed and manual document stress handling which can be cumbersome. Furthermore, ICTs allow strong error detection which in turn eliminates the need for reworks and the extra cost related to it, when executing a project. This leads to better customer satisfaction (Krishnamoorthy, 2017). The speed of accurate information transmission, reflects the pace of the project delivery, leading to customer satisfaction (Tanga et al., 2021).

2. 3 Communication and Collaboration

Construction projects require varied groups of people, operations, and organizations to accomplish an ideal objective. Thus, collaboration, coordination, and data communication between different parties are important for successful project execution (Tanga et al., 2021a, b). Moreover, Sekou (2012) affirmed that ICTs can be utilised as the empowering tool of knowledge and collaboration management via knowledge warehouses, management systems, enterprise planning, decision support systems, groupware applications, use and establishment of database knowledge discovery.

2. 4 Elimination of Time-Consuming Processes

Information Communication Technologies help in construction project scheduling, which aims to coordinate the resources including equipment, materials, and labor with project work tasks, over time. A project can be completed as quickly as possible with the help of effective scheduling, which can also help with the timely acquisition of necessary supplies and the elimination of problems caused by production constraints (Tanga et al., 2021a; Nayak and Mohanty, 2012). In contrast, bad scheduling can result in enormous waste as employees and equipment wait for the availability of essential resources or the execution of preceding activities. The lack of a proper scheduling can also cause delays in a project's completion, which can be disastrous for owners who are eager to begin using the newly built facilities (Tanga et al., 2021a; Nayak and Mohanty, 2012).

2. 5 Reduced Cost and Information Storage

Information and communication technologies can help organisations succeed in their operations by reducing costs and saving time through better cooperation. This is because ICTs improve client interactions through improved consumer feedback and communication systems, quicker access to important information, improved data storage, monitoring, and safety (Ballan, 2011; Savvides, 2015). Moreover, Tanga et al. (2021b) explained that for instance cloud storage offers superior functionality and performance requirements, portable needs, cost demand, and other benefits over the prior type of storage, which required significant maintenance costs, additional infrastructure investment, and the addition of servers to meet the rising demand. This can therefore boost the embracing of ICTs in the construction sector.

2. 6 Improved Project Administration

Burger et al., (2018) stressed that ICTs in the building sector are used for the expanded speed of conveyance and work execution, efficacy exchange, upgraded quality, and arrangement of the large scope of administrative services through their automation ability. Its utilisation and the mix of computer applications inside the professional's services build the dimension of efficiency in the building sector and grow the scope of data accessibility and the services offered while accelerating building work and lessening costs (Ahuja, 2009). However, Nguyen (2015) noticed the deficiency of comprehensive ICTs by the administration and supervision team. This affects the adoption of ICTs on construction projects.

2. 7 Business Data Integration and Nature of Business

The construction business is very vast and receives data or information from various sources and stakeholders. This information needs to be organised and integrated into a single and trusted storage which is possible with the adoption of ICTs (Tanga et al., 2021b). However, the nature of the construction business is to be considered as big projects require more stakeholders, more information, and administrative work involving the need for ICTs compared to small businesses (Tanga et al., 2021a, b). This applies to a certain category of ICTs only because for instance, emails are used in both small and big businesses (Tanga et al., 2021a).

2. 8 Process Improvement and Site Management

Peansupap (2004) & Sekou, (2012) opined that ICT dispersion in the building industry is a significant driver for improving the productivity and efficiency of the industry. In line with this, Samuelson (2002) & Sweis (2010) have submitted that ICT use was generally high in the facility management, and its utilization by workers and site labourers in the production procedure was shockingly low. They furthermore put forward that, some part of the poor efficiency figures in the building sector could be clarified by the way data is needed and the communication practices in building sites which are not satisfactorily met. Until now, the industry has experienced lots of exertions to improve efficiency. With the assistance of ICT tools and different its applications, have demonstrated that there is noteworthy potential for productivity and efficiency improvement in the building industry and that ICT is playing a great role in it. (Samuelson, 2002). During site management and process improvement, ICTs will help in the data collection, safety precautions (hazards alarm), daily report production, and delivery of needed data and information (Sekou,2012).

2. 9 Electronic Commerce and Electronic Procurement

Parida & Örtqvist (2015) asserted that information communication technology (ICT) is a tool that can be used to improve electronic procurement in the building industry. Electronic procurement also known as e-procurement can be categorised into electronic purchasing (e-purchasing) and electronic tendering (e-tendering) in the construction industry. Electronic tendering is utilized for different purposes such as selecting the best contractors and suppliers and resolving tender problems. Nawi (2016) put forward that e-procurement has been created for the selection of a reasonable number of suppliers, the best price and quality relation, and the best contract plan. Sekou (2012) opined that e-tendering helps to access the organization's publications and notices of tenders inside and outside the country for bidding internationally. E-procurement thus influences the establishment of a market for building amenities and construction materials. This is thus a driver since it allows smooth and improved construction business processes.

3. Research Methodology

Regarding this study, a quantitative research methodology was selected to assess the main ICT adoption drivers in the construction sector. An electronic questionnaire was created as the data collection method to rate the participants' knowledge. The information gathered from researched literature was used to create the questionnaire. The South African province of Gauteng was chosen as the study's field of investigation. This area was chosen because it is close to the researchers and because it has the research issue that this study is trying to tackle. The Gauteng province in South Africa served as the study's target market, which comprised civil engineers, construction managers, quantity surveyors, architects, and industrial, electrical, and mechanical engineers. In Gauteng province, there are 1054 participants in total. The sample size of 289 was attained using the Yamane sample size formula and a degree of precision of 5%. To contact the population through their professional bodies, a convenient and random sampling method was adopted since it offers each person a chance to be chosen or included in the sample while working with the available set of participants. Eighty-five properly completed surveys served as the basis for this analysis. This indicates a 30% response rate. Previous research has demonstrated that a response rate of 20–30% is statistically appropriate for online social science research (Knaub, 2013). To rank the advantages of ICT tools, the data were analysed using the mean item score (MIS) and standard deviation (SD), and Kruskal-Wallis. Kruskal-Wallis was used to compare the participants' opinions based on their years of experience. Additionally, the data sets' dependability was assessed using Cronbach's alpha reliability test, which produced a result of 0.9000, which indicates a high level of consistency.

4. Findings and discussion

Based on the examination of the collected data, all of the respondents are members of a professional organisation, hold academic degrees, and have an average of six years' experience working in the construction sector. The participants' backgrounds also revealed that they have a sufficient level of professional training and years of experience in the construction sector. This implies that they are qualified to answer the research question. Table 1 showed the participants' ranking of the drivers of ICTs in the South African construction industry. It discovered that Elimination of Time-consuming Processes and Communication and Collaboration were the leading drivers of ICT use with a mean score of 4.25 and a standard deviation of 0.84 respectively; followed by maximized project profitability as the third most eminent driver of ICT use with a mean score of 4.20 and standard deviation of 0.86. At the bottom of the ranking, Electronic Commerce and Electronic Procurement and Reduced cost were ranked eleventh with a mean score of 4.04 and standard deviation of 089 and 0.98 respectively while Nature of Business ranked the least with a mean score of 3.89 and a standard deviation of 0.86.

Table 1. Drivers of ICT tools in the construction industry

Drivers of ICT use	$\bar{x}$	Σ	R
Elimination of time-consuming processes	4.25	0.84	1
Communication and Collaboration	4.25	0.84	1
Maximized Project Profitability	4.20	0.86	3
Information Storage	4.18	0.82	4
Customer Satisfaction	4.17	0.83	5
Business data integration	4.16	0.75	6
Improved Project Administration	4.16	0.75	6
Process Improvement and Site Management	4.14	0.82	8
Speed	4.13	0.94	9
Increased profit	4.05	0.90	10
Electronic Commerce and Electronic Procurement	4.04	0.89	11
Reduced Cost	4.04	0.98	11
Nature of Business	3.89	0.86	13

σ = Standard Deviation; $\bar{x}$ = Mean; R= Rank

Table 2. Kruskal-walli’s test result

Variable	P–Value
Increased profit	0,288
Speed	0,253
Communication and Collaboration	0,313
Business data integration	0,122
Process Improvement and Site Management	0,107
Electronic Commerce and Electronic Procurement	0.088
Information Storage	0,382
Reduced Cost	0,293
Customer Satisfaction	0,164
Nature of Business	0,525
Maximised Project Profitability	0,207
Improved Project Administration	0,605
Elimination of Unnecessary Processes	0,057

A Kruskal-test Walli's was used to compare the participants' perspectives based on their years of experience, as can be seen in table 2. All of the specified "drivers" were found to have no significant difference in mean values as all p-values are greater than 0.05. Although "Elimination of Unnecessary Processes" p-value recorded of 0,057 is close to 0.05, it is still exceeding 0.05.

From the analysis result, it is evident that all the variables are actual drivers of Information and Communication Technologies adoption with each of them having a mean item score above 3.00 known to be the 5-point Likert scale average. As indicated from the survey result elimination of time-consuming process is the highly-rated driver of ICTs. The implementation of ICTs helps to eliminate processes that are manually handled which is time-consuming. This is supported by the study of Krishnamoorthy, (2017); Tanga et al. (2021a, b) who stated that allowing the sharing of bulky documents while ensuring information and data security at the same time which is the case of cloud storage. The study also reveals that communication and collaboration is a driver of ICTs. This is because for projects to be successful, there is a need for constant exchange and communication of information among project parties because the construction business involves several groups of people coming together to fulfil project objectives (Zhang and Yuan, 2016 and Cheung, 2013). Sekou (2012) explained that this exchange of information is achieved through the use of tools and data storage systems such as decision support systems, knowledge warehouses, management systems, as well as databases. The study shows that maximised project profitability is one of the drivers of ICTs. The adoption of ICTs in the construction industry leads to organisational growth through improved performance that is made possible via fluent and rapid information transfer amongst project parties. Furthermore, ICTs make it possible to handle data, facilitating simple organizational tasks and data flows as well as wise business decisions based on the information at hand, maximizing project profitability and giving a company a competitive edge over its competitors (Tanga et al. 2021b). In line with the submission of Ballan (2011) and Savvides (2015) information storage is a driver of ICTs adoption, the author affirmed that ICTs enhance customer engagement by enhancing systems for receiving customer feedback and communicating with them, providing faster access to crucial information, and improving data preservation, surveillance, and safeguarding. This will enable customer satisfaction and therefore promote company success. Moreover, Tanga et al. (2021a) pointed out that the implementation of ICTs does only provide customer or client satisfaction but also quickens the pace of project completion due to the fact that time consuming processes are eliminated from the shifts from manual documents handling to electronic data processing and handling. Thus, fast project delivery made possible through quick information exchange will allow good company reputation and permit the organisation remain in business for a very long period of time.

5. Conclusions and Recommendation

The research was designed to evaluate the drivers of ICTs adoption in construction organisations. According to the literature, the use of ICT tools has increased construction work production and effectiveness in the building industry sectors throughout time by managing tasks including engineering design, architectural drawing, and bill of quantities preparation. These benefits positively influence many construction organisations to adopt ICTs. The collected data revealed that the most common drivers of ICTs adoption encompass the elimination of time-consuming processes, communication and collaboration, and maximised project profitability. In light of this research, it is recommended that construction companies offer their employees education on how to use various ICT tools. This will keep professionals abreast of cutting-edge ICT innovations as well as encourage continuous ICTs adoption. Additionally, the construction sector will be able to more effectively manage its information which is one of the factors that promotes construction projects' success. Furthermore, this work recommends that project members need to accept the cultural change that comes with ICTs adoption to facilitate its adoption. Besides that, financial support from NGOs and the government is needed to help organisations that are struggling financially. This study's concentration on the Gauteng province of South Africa constitutes a limitation. Further research can analyse other provinces to get a broader picture of ICT usage in the South African construction sector.

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Contributing Factors to Relational Conflict in Construction Project Delivery in South Africa

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Abstract

The effectiveness of the relationship among key stakeholders influences the progress of a building project. If this relationship weakens, it may result in a number of disagreements that frequently result in litigation or even delay in project delivery. Stopping this from happening depends on identifying the contributing factors to relational conflict in project delivery. This has become necessary particularly in South Africa (SA), considering the rising cases of poor project performance in the country with one of the root cause being poor relationship among project stakeholders. Hence, this study examines the contributing factors to relational conflicts in construction project delivery in SA. Adopting a survey design for the study, construction industry professionals in Guateng Province, SA were the respondents and a total of one hundred seventy-five (175) questionnaires were administered to them. One hundred and twelve (112) of those were returned and deemed appropriate for the study. Utilizing percentage, mean item score, standard deviation, and Kruskal-Wallis, the collected data was analyzed. The findings reveal the contributing factors to relational conflict in construction project delivery in SA which includes opportunistic bahaviour, attitude/personality traits, miscommunication, coordination of trades/resource allocation, and working condition among others. The findings of this study provides information to project stakeholders in the country on the contributing factors to relational conflicts and necessary steps to take during project planning to ensure relational conflicts do not occur during project delivery. Doing this will contribute significantly to project success in the country.

Keywords

Conflicts, Construction, Contributing factors, Project delivery, South Africa.

1. Introduction

Construction projects involve a variety of stakeholders, each with their own set of concerns and requirements that must be addressed in order for the project to be successful (Olander, 2007). Construction is a collaborative endeavour in which success is heavily reliant on stakeholder commitments (Leung et al., 2004) and as such it is very crucial for the relationship between the stakeholders to be healthy, fair and lucrative. Construction project stakeholders in a project might come from the inside or the outside of the organisation. Those from the inside have an undeviating effect on the organisation's decision- taking process, whilst those from the outside are influenced by the decisions of the organisations (Atkin & Skitmore, 2008). In a typical construction project, the quality of the relationship between critical stakeholders (client, consultant, and contractor) influences project progress. If this relationship is harmed, it can lead to a variety of disputes, which usually end in litigation or even the delays the delivery of the project (Ogbeifun et al, 2018). The truth is that each stakeholder has a certain job and responsibilities, as well as expectations or interests that must be met. Managing these disparate interests, which requires skill and pragmatism in controlling the relationship makes it easier to reach the project's goals but also can lead to conflict if not well managed. The likelihood of a project experiencing severe disputes increases if the stakeholders are not managed efficiently and their concerns and objectives are not addressed.

PMI (2017) opined that conflicts among stakeholders are unavoidable due to a large number of stakeholders involved in building projects and the significant variability of situations arising from construction processes. Depending on their interests or involvement in the project, construction projects performance can be affected negatively/positively by the various interests of the stakeholders. There is no denying that having many stakeholders in a building project is sure to cause issues among participants (Aghimien et al, 2019). However, healthy stakeholder relationships are extremely critical to the construction organisation's success as the effect of the relationship between the construction stakeholders can be very damaging to the project's objective. The success of a project is mostly determined by the project stakeholders and the project structure, which includes time, cost, and quality (Davis, 2016). Cost and time overruns, loss of production and profit, and harm to business relationships are all outcomes of disagreements among project stakeholders. If neglected, these conflicts may hinder project completion and damage stakeholder relationships, affecting project completion. According to Sinesilassie et al. (2017) and Vaux & Kirk (2018), the following are some of the relational conflicts a construction project could encounter; delays in project delivery, miscommunication about project intentions, disrespect, poor teamwork and ultimately, poor performance by the organisation.

Ogbeifun et al. (2018) posited that although construction project disputes are unavoidable at times, they can be managed from the start of a project, particularly the disputes that arises from relationship breakdown among the project stakeholders. However, this can only be possible if the factors that contributes to relationship breakdown among project stakeholders are identified from the onset. According to Vaux & Dority (2018), there are different types of relationship conflict that could occur among stakeholders of a project, which includes task conflict among others. Wu et al. (2017) posited that these relationship conflicts between stakeholders can arise during any stage of a building project. Hence, it is important to first identify the contributing factors to relational conflict in project delivery. This has become necessary particularly in South Africa (SA), considering the rising cases of poor project performance in the country with one of the root cause being poor relationships among project stakeholders.

2. Materials and Methods

The study took a post-positivist approach in terms of philosophy, employing quantitative research that was carried out using a questionnaire survey. The questionnaire was divided into two segments, with the first segment intended to elicit background data from the respondents. The second segment tried to address the contributing factors to relational conflict in project delivery. The respondents, who are construction professionals were requested to rate the significance of the contributing factors to relational conflict in project delivery in the South African construction industry using a 5-point Likert scale, with 5 being Strongly significant, 4 being significant, 3 being moderately significant, 2 being slightly significant , and 1 being not significant. The study population were made of qualified construction professionals (engineers, architects, quantity surveyors and construction managers) who are working in South Africa and had at least five years of work experience. Due to time and financial restrictions, convenience sampling was used for the study. One hundred and seventy-five (175) questionnaires were sent out to the construction professionals and one hundred and twelve (112) were received and considered appropriate for investigation. Standard deviation, percentages, mean item scores, and Kruskal-Wallis tests as adopted by Otasowie & Oke (2022) were used to analyse the collected data. Using the Cronbach's alpha test, which yielded an alpha value of 0.873, the study validated the questionnaire's reliability. Given that the alpha score is over the cutoff point of 0.6, confirms the questionnaire's high degree of reliability (Tavakol & Dennick, 2011).

3. Results

Professionals in the construction sector from South Africa participated in the survey. The profession with the most involvement (24.5%) is engineers. Following are quantity surveyors (19.6 %), trade craftsmen (17.6%), construction managers (15.7%), architects (13.8%), and health and safety agents (8.8%). The majority of these respondents (61.8%) hold bachelor's and honours degrees, while the other levels of education are masters, doctoral, and higher diploma degrees, respectively, with 10.8%, 2.9%, and 24.5%. The total number of respondents had an average working history of 7.6 years, which is a remarkably long period of time in the field. These findings suggest that the study's target respondents, who were construction professionals, were fairly represented and that they had a sufficient degree of education to comprehend the study's questions (Otasowie & Oke, 2022). Also, the answers to these queries were based on a large amount of professional expertise.

Furthermore, the contributing factors to relational conflict in project delivery are shown in Table 1 below, ranging from highest mean to lowest mean. As can be seen, factors with the same mean were ordered according to how much they deviated from the mean (standard deviation). The mean standard error (SE) is a definition of the standard deviation. The standard deviation reveals what the mean of the observed data was. A modest standard deviation illustrates a situation where most data points are near to the mean, whereas a high standard deviation indicates a data point that deviates much from the mean (Field, 2005). As a result, this was used to rank the factors with a similar mean. The average of the replies received from each responder makes up the mean for each factor.

The results show opportunistic bahaviour as the highest ranked driver (MIS=4.36, SD = 0.91). This was followed by Attitude/personality traits (MIS=4.35, SD=0.85); miscommunication about project intentions (MIS=4.32, SD =0.85); coordination of trades/resource allocation (MIS=4.20, SD=0.82); adversarial industry culture (MIS=4.20, SD=1.00); working conditions (MIS= 4.17, SD=0.97); unfair risk allocation (MIS=4.16, SD =0.85); Unrealistic information expectations (MIS=4.13, SD=0.93); disrespect (MIS=4.12, SD =0.94); bullying (MIS=4.08, SD =0.91); procrastination (MIS=4.07, SD=1.00); and ranked last was credit stealing (MIS=4.03, SD =1.01).

Table 1. Contributing Factors to Relational Conflict in Project Delivery

Factors	Mean	Standard Deviation	Rank
Opportunistic bahaviour	4.36	0.908	1
Attitude/personality traits	4.35	0.854	2
Miscommunication	4.32	0.846	3
Coordination of trades/resource allocation	4.20	0.821	4
Adversarial industry culture	4.20	0.959	5
Working conditions	4.17	0.970	6
Unfair risk allocation	4.16	0.853	7
Unrealistic information expectations	4.13	0.934	8
Disrespect	4.12	0.941	9
Bullying	4.08	0.913	10
Procrastination	4.07	0.845	11
Credit stealing	4.03	0.567	12

To compare the responses of the respondents according on their different construction professions, a Kruskal-Walli's test was conducted. It was found that while the responses for some contributing factors to relational conflict in project delivery in the South African construction industry, such as opportunistic bahaviour, attitude/personality traits, miscommunication about project intentions, coordination of trades/resource allocation, working conditions and unrealistic information expectations, do not statistically differ from one another significantly. However, they do differ from one another significantly statistically in the case of other factors. Table 2 below presents the result.

Table 2. Kruskal-Wallis Test Showing P-Values for Contributing Factors

Factors	P-Values
Opportunistic bahaviour	0.064
Attitude/personality traits	0.050
Miscommunication	0.072
Coordination of trades/resource allocation	0.053
Adversarial industry culture	0.008

Working conditions	0.058
Unfair risk allocation	0.002
Unrealistic information expectations	0.071
Disrespect	0.001
Bullying	0.041
Procrastination	0.000
Credit stealing	0.034

4. Discussion

The involvement of several stakeholders with a range of interests in construction project's operations and results is a key factor to success (Abidin, 2010). The conception and implementation of initiatives, as well as guaranteeing their success, depend heavily on stakeholder relationship (Eyiah-Botwe et al., 2016). Cost and time overruns, loss of production and profit, and harm to business relationships are all outcomes of disagreements among project stakeholders. If neglected, these conflicts may hinder project completion and damage stakeholder relationships, affecting project completion. Based on the result above, opportunistic bahaviour is the first ranked contributing factor to relational conflict in project delivery in the South African construction industry. This was even made clear by the Kruskal-Wallis test conducted, as the various construction professionals in the South African construction industry agreed that opportunistic bahaviour is a significant contributing factors to relational conflict. Opportunism defined by Williamson (1975) as "self-interest seeking with guile" implies that actors deviate from the terms of agreement if it will benefit them more to do so. Eriksson (2006) also includes participants deviating from the spirit of agreement in its definition of opportunism in that, while contract participants might not actually break the terms of agreement, opportunistic behaviour would include such things as lying, tardiness, and intentionally unclear statements and bluffing. A key idea in the assessment of transaction costs is opportunism, which is crucial for economic activity involving relationship-specific expenditures. In earlier studies, "lying, stealing, cheating, and premeditated attempts to mislead, distort, conceal, obfuscate, or otherwise confuse" have been conceived and labeled as "blatant" opportunism. An example of opportunistic bahaviour can be when contractors operate in a way that serves their own interests while taking advantage of their clients. Examples of this conduct include breaking promises, shirking responsibilities, and breaking explicit or tacit agreements (Lu et al., 2016). In both professional and academic settings, controlling and preventing opportunistic conduct is a crucial concern. In construction works, opportunistic behaviour from any of the participants can result in relational conflict, which cause delays in the construction period, lower project quality, and affect the two parties' ability to work together. Although, most opportunistic behaviours in construction projects have been traced to the contractors, it is important to note that even clients of projects can exhibit opportunistic behaviours. Example of this can be client delaying payment to consultants for consultancy services rendered, transferring risk to contractors and yet shying away from paying for the risk, and clients refusing to adapt to changing circumstances but rather insist on same work order or specifications irrespective of the greater cost and risk imposed on the contractor among others. The problem with these behaviours is that confidence fostered in cooperation are damaged by the presence of opportunism in projects, and hence, weakens the collaboration. Opportunism is viewed as a big threat and a crucial factor against good corporate collaboration, according to Williamson (1975), who claims that it impacts the growth of trade issues between partners.

Furthermore, attitude/personality traits is a contributing factor to relational conflict in project delivery in the South African construction industry. In fact, it is ranked second based on data collected from the various professionals in the industry and was even made clear by the Kruskal-Wallis test conducted. According to Vaux & Kirk (2018), conflicts between people that are characterised by unpleasant feelings, tension, conflict escalation, and increased stress are manifestations of personality traits that contribute to relational conflict. Several earlier studies have noted the significance of personality traits. Personality trait is a person's unique set of ideas, feelings, and behaviours, but there are psychological processes that give rise to those behaviours (Danja et al., 2021; Barza & Galanakis, 2022). Dumfart

& Neubauer (2016) posited that those with better attitude/personality traits do better in school, on the job, in their physical health, in their relationships, and they live longer. People require relationships in both personal and professional circumstances (Blustein, 2011). Relational management views stakeholder relationships strategies as essential to accomplishing project goals, and attitude/personality traits is a crucial component of relationship. This explains the significant link between relationships and project success (Pinto et al., 2009). Also, considering the relationship of the principal and agent that has been well documented by scholars in construction management literature (Oteng, 2016; Yallew et al., 2018), it is imperative that a positive attitude/personality traits is needed to achieve project goals.

Miscommunication is another significant contributing factor to relational conflict in project delivery in the South African construction industry. It is ranked third based on data collected from the various professionals in the industry. This corroborates Brockman (2014) and Vaux & Kirk (2018) that one of the most frequent cause of relational conflict that has been discovered is a lack of communication and information withholding. Lack of communication was characterised as a behavioural issue by Jaffar et al. (2011). According to Gardiner & Simmons (1998), project teams are frequently put together without having worked together before, which can lead to misunderstandings once the project's intensity is at its peak. Together, these misinterpretations and inexperience frequently cause communication issues that end in relational conflict. Relationship conflict frequently results from a lack of communication abilities essential to sustain a solid flow of communication when operations are closely interconnected and the pace is fast (Vaux &Kirk, 2018). It is important to note that conflict in relationships and issues with communication feed each other in an unhealthy cycle. Communication is impeded when there is relationship conflict, and if there are issues with communication, relationship conflict will frequently follow, creating a vicious cycle.

Coordination of trades/resource allocation is yet another significant contributing factor to relational conflict in project delivery in the South African construction industry. It is ranked fourth based on data collected from the various professionals in the industry. Also, there is no significant difference in how the construction professionals responded to this factor. According to Gunarathna et al. (2018), one of the main causes of relationship conflict in construction projects is the interconnectivity between project tasks that was brought about by the coordination of trades. Furthermore, trade coordination was identified by Brockman (2014) as a major source of relationship conflict. Even high levels of multidisciplinary participation among subcontractors are a major cause of relationship conflict (Gunarathna et al., 2018). This current study supports these various studies on coordination of trades being a contributing factor to relational conflict in project delivery.

In addition, working conditions is another significant contributing factor to relational conflict in project delivery in the South African construction industry. According to Chen et al. (2017), Long hours at the office contributes to relationship problems. This position was corroborated by the current study. Gunarathna et al. (2018) also identified workmanship as a significant contributing factor to relationship conflict. Managing subcontractors to reach the requisite quality outlined in specifications was the root of this conflict. Rework, understanding of the installation procedure, and delayed progress related to quality problems were also noted.

Other significant contributing factors to relational conflict in project delivery in the South African construction industry identified from the study include adversarial industry culture; unfair risk allocation; unrealistic information expectations; disrespect; bullying; procrastination; and credit stealing.

5. Conclusions

Relational conflict is typically seen as counterproductive involving friction, tension, frustration, and occasionally animosity that have a negative impact on team performance, information sharing, and the creative thinking needed to solve complex problems. This study examines the contributing factors to relational conflict in project delivery in the South African construction industry in a bid to identify and manage the contributing factors so as to prevent relational conflicts in construction project delivery. The contributing factors were obtained from the review of relevant literature and presented to the construction professionals in the country. The results of the study show that opportunistic behaviours by project stakeholders is the most significant contributing factors to relational conflict in project delivery in the South African construction industry. Attitude/personality traits, miscommunication, coordination of trades/resource allocation, working conditions among others are additional contributing factors to relational conflict in project delivery in the South African construction industry. In other to mitigate these contributing factors, control mechanisms can be adopted with the purpose of motivating, or deterring certain behaviours for the goal of aligning the interest of the stakeholders with the project. Also, one important factor for mitigating relational conflict in construction project delivery is good communication. By communication, it means a project team's desire to provide information willingly at all times, either through formal or informal means. These have been found to mitigate relational conflicts. The findings of this study provides information to project stakeholders in the country on the contributing factors to relational conflicts and necessary steps to take during project planning to ensure these conflicts do not occur during project delivery. Doing this will contribute significantly to project success in the country.

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The Implications of Interim Payment Certificate in UK: A Literature Review

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Abstract

The appropriate measurement and valuation of construction works is between the crucial aspects of successful project management. This takes place following traditional surveying methods and inspection techniques, however, both clients and contractors cannot properly follow-up monthly expenditures and payments without following a strict interim payment certificate (IPC) system. Also, setting the right payment methods and conditions promotes financial transactions which help preventing severe financial losses if not structured carefully in early stages of agreements. On contrary, late payments and less certified amounts from client side have many negative consequences including increased disputes, delivery delays, liquidated damages, and other financial losses for stakeholders. This study, therefore, aims to focus on the importance of the IPC system to facilitate the payment process with fewer deputies, using qualitative research approach analysing the available relevant literature focusing on residential projects in the UK. The issues arriving from IPC are divided into six main themes are discussed with a reference to relevant literature. The results indicate that without proper follow-up contractors do not get paid properly and even projects might get terminated mid-way, as cash flows are significantly constrained. Recommendations on improving on the IPC are provided along with areas for further research.

Keywords

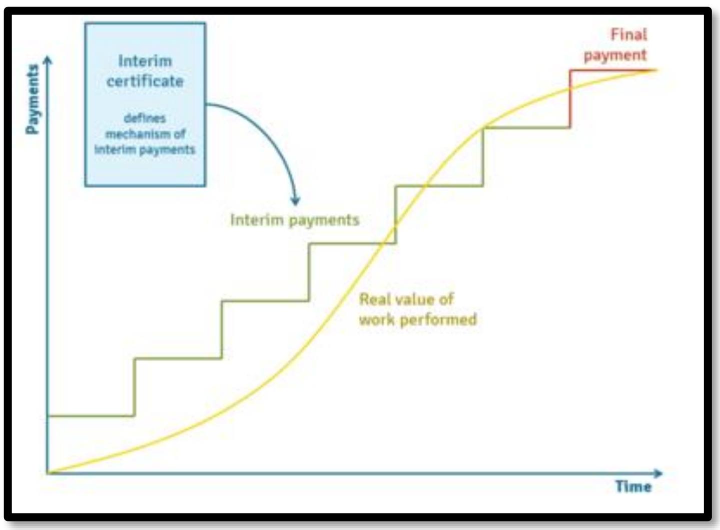
Construction Management, Interim Payment Certificate, Construction Contracts, Economic and Finance, Contracting

1. Introduction

The construction industry is one of the biggest industries when it comes to the point of civilized societies (Umar and Egbu, 2020). Its projects require large capital investments to get delivered within the approved deadlines. However, quite often clients do not pay the due amounts on time, leading to arguments between constructors and clients (Van der Hoven, 2013), which resulted in the inception of the "interim payment certificate". Therefore, the researcher aim is to shed light on this topic by conducting a detailed study into the "interim payment certificate" through a qualitative study design. Since projects in the industry, especially in the housing sector, are complicated as well as hierarchical in nature, payment disputes are common among all the involved parties (Zhang *et al*., 2009). Furthermore, clients sometimes do not clear the payment after the competition of a project, which is why contractors consider this as a critical issue.

Setting the right payment method and condition is one of the most essential factors of all financial transactions, which might result in severe financial losses if not structured or determined carefully in the early stage of an agreement. The concept of "early delivery and late payment" is a common phenomenon that is widely circulated among various businesses all over the world (Stewart *et al*. 2019). According to Ahmadisheykhsarmast and Sonmez, (2018), among the most prominent problems that contractors face in the construction industry are the issues related to delays in payments and disputes between all involved parties. Time/cost overruns, business bankruptcy, as well as difficulties in managing cash flows are the consequences of withholding and dispute of the payments. In 2012, the "Government of New South Wales" has conducted analysis aiming to develop the consequences of disputes and insolvency in the construction industry. The result of the investigation shows that surpassing the payment time, lack of assurance for payments, and refusal to pay the due amounts are three consequences of contractual disagreements in the industry (Ahmadisheykhsarmast and Sonmez, 2018). There is high requirement to come up with effective strategies so that the company can cope up with the respective situation to mitigate the working barriers. This mechanism should ensure that all the latest and innovative technologies should be taken into consideration so the targeted aims of attainment of payment on time could be reached (Luo *et al.*, 2019).

There is a huge gap between IPA and IPC that needs to be reduced with effective strategies (Nizza, Farr and Smith, 2021). The mechanism of IPC is a concept which is associated with payment certification that is generally issues by engineers, so that they can attain payments under clause 14.6 under the FIDIC regulations. According to the UK government data, the construction industry in the UK accounts for employing more than 3.1 million workers which is 9% of the total workforce (Gov.uk, 2019). In addition, The Housing Grants, Construction, and Regeneration Act 1996 highlights that the client in a construction contract, more than 45 days, is entitled to the "interim" phase of payments (Legislation.gov.uk, 2022). Figure 1 illustrate that based on payment and time to evaluate the interim payments and the real value of the desired work performed, all the payment modes can be attained through the process of interim payments as it adds a huge value to the completed project.



Fig,.1. Interim payment Certification (Das *et al*., 2020)

Construction projects are unique with various scales that require a great number of both financial resources (Luo *et al.* 2017). Provided by engineers, the IPC shows how contractors get progress payments while the construction is under process. According to Durdyev, Omarov and Ismail (2017), payment disputes and construction delays have become most prevalent, and there is a need to focus on a transparent payment solution. Developing a better understanding to know the reasons behind the consistent payment issues in this sector might not be enough to properly avoid having to trade with them.

There have been several studies on payment aspects within the construction sector. There is still limited clarity on the different issue such as "what does the term "interim payment certificate",, "how effective is the concept of IPC when it comes to the point of payment transparency in the construction industry?", and "are clients and contractors making the payment system transparent by focusing on IPC meeting contract agreement?". The aim of this research is, therefore, is to critically analyse the concept of IPC in the construction industry, specifically in residential projects, and examine its importance by conducting a qualitative study from the perspective of contracting entities operating in the UK. The objectives include identifying the concept of IPC for residential projects from the perspective of contracting entities operating in the UK. It also considers the effects of the IPC on the economic downturns of the residential sector and analyse how effective the concept of the IPC is when it comes to the point of payment transparency in the industry as well as how effectively contractors and clients are ensuring IPC meeting contractual agreements.

In addition, the research has also laid its focus on the guidelines under the JCT contract “JCT Constructing Excellence Contract”. Hence, the payment structure of the contract is considered where it has been evaluated that a single payment is generally made for various scopes of work. This mechanism is also known as “first and final payment”. According to Khan and Ali (2018), payment issues are one of the major reasons that there are communication issues within a construction project, which lead to the delay in project completion. Therefore, this paper analyses this issue faced by multiple shareholders and parties involved by presenting the concept of an IPC especially in the residential project in the UK.

2. Research Methodology

There are several types of philosophies used in research including positivism, constructivism, and objectivism (Dougherty *et al*. 2019). Various reasons are behind the selection of the positivism research philosophy. The focus of this study is on the concept of IPC and how the impact on the clients and contractors. Therefore, there is a need to observe the real scenario. It can also be seen that positivism research philosophy is dependent on observation for gaining factual knowledge. Therefore, the requirement is completely fulfilled. To analyse the transparency in the interim payment system, there is also a requirement for clear observation (Alharahsheh and Pius, 2020).

There are various designs of research such as exploratory, descriptive and explanatory (Wipulanusat *et al*. 2020). The design of the research is the framework of the methods that are selected by the researcher to conduct the given context. The researchers selected descriptive research design. It is the type of research aims to obtain the information to describe the situation, phenomenon, and population. The IPC gives contractual advantage to clients to make payments to contractors in workplaces. Construction laws apply in the construction industry that is derived from the other area of the general laws (Ramsey, 2022). The IPC in the construction industry depends on the performance of the employees and precise they are on the valuation of the work so there is a need to select the right participants to complete the research. Therefore, the descriptive design is appropriate to select the participants of the research who give their opinion.

Using the secondary data collection method that is thematic and article review, the research gets the best information from the published articles, books, and journals for the growth of the IPC system in the workplace. Corporate social responsibility (CSR) in the organisation makes interim commitments to the stakeholders of the project work which is a major part of the growth of the economic condition of the construction industry (Wentzel *et al*., 2022). In addition, the journals or articles hold the impact of IPC in the workplace for the growth of the skills of the employees.

The secondary data are collected through journals, and books known as qualitative analysis. In addition, the context of articles is discussed as the qualitative data. The lack of knowledge of the employees can affect the workplace and the performance of the organisation in the project. The construction industry faced many challenges in the low performance in the workplace (Li *et al*., 2019). Data analysis is a tool that involves multiple activities to clean, gathers, and analyse the data for the context of research. The structured and unstructured data is the predefined model such as a traditional database.

3. Results and Analysis

After reviewing the current literature different themes have been developed based on the data collected form the literature review. The results and analysis section is therefore divided in several sub sections based.

3. 1 Theme 1: Securing interim payments in construction projects through a block chain-based framework

According to Das *et al.* (2020), IPC provisions in the UK-based industry are susceptible to unfair practices. They have highlighted that in this sector, all the participants with different financial capabilities belong to various organisations. They are bound to follow the regulations provided in the IPC certificate. However, due to the complex nature of the IPC system, project managers as well as clients, usually do not tend to trust each other, which results in project quality deterioration. The following observation has been collected from different research:

- With the help of block chain technology, stakeholders can facilitate secure, fast, and low-cost international payment processing services.

- The use of “encrypted distributed ledgers” tends to offer reliable real-time verification of all the transactions in this sector without having intermediaries like correspondent banks and clearing houses.
- An integration of the block chain system could lower the time required for payment processing from several days to only a few hours that reflect on saving running costs and decrease the disputes related to delays.

3.2 Theme 2: Safety climate in the construction industry

According to Umar and Egbu (2018), IPC is much needed to make the transactions in the industry much smoother; however, one must not forget the impact on employee safety. The most important aspect is provisioning utmost security, health, and safety to ground-level workers, as well as engineers working on sites. As per the study, there is a need to conduct safety climate assessments that could enhance the quality of safety tools as well as workers' well-being. The results of the interviews also indicated that a better assessment of public health and well-being is as important as initiating the IPC system. Also, the relationships between health and safety assessments and IPC mechanisms are included in most contracts’ payment conditions, and clients’ entitlements to deduct from contracts’ payment amounts.

3.3 Theme 3: IPC and “Earned-value reduction techniques” in the construction sector

According to Demachkieh and Abdul-Malak (2019), progress payment certifications and valuations are between the unique factors in the construction industry, as these aim to make construction administration better and well-structured. If certifications and valuations are not properly administered by contract administrators might set the base for disputes between clients and managers. In addition, there are many reasons that residential projects fail, some most important reasons found by the researchers are:

- Quality-related reductions and discrepancies in the measurement of project quantity could result in payment withholdings.
- The incompatibility with the estimated and planned schedule for a project, regardless of the size of a residential project.

3.4 Theme 4: Residual risks of payment

In every business engagement, the obligor and oblige of cost-related adherence in the construction industry are mostly governed by a contract based on the IPC agreement. The study paper developed by Sanni *et al.* (2020), critically examines various residual risks related to the most famous payment modes in the industry based on JCT and FIDIC contracts. As per the findings of this paper, proper adherence to the highlighted two payment modes can enhance the traction based on the IPC system in the UK.

- “Sub-Clause 14.6 (Issue of Interim Payment Certificates)” highlights the need for “Advance Payment”.
- “Sub-clause 14.6 and 14.7” highlight “Interim Valuations”- a client needs to clear the payment in every IPC certificate within 56 days after an engineer gets all the documents.
- “Sub-clause 14.8” is all about “delayed payment” and is applicable when a contractor does not get the payment adhering to “clause 14.7”.

The Construction Management Contract (JCT-CM) from the JCT is intended to be used on projects when different trade contractors are assigned by the employer, each has its own distinct contractual obligations to build the works (Designing buildings, 2017) which include the following new characteristics:

- “Incorporation of the provisions of the JCT Public Sector Supplement 2011” (Purba and Yuri Prastowo, 2020).
- “Provisions for the grant of Performance Bonds and Parent Company guarantees”.
- “Adjustments to reflect the Construction (Design & Management) Regulations 2015 and the Public Contracts Regulations 2015”.

3.4 Theme 5: Late and improper way of payment to the contractors in residential projects:

According to the findings of Bolton *et al*. (2022), issues related to late and improper way of payment to contractors are between the worst issues in the UK-based construction industry in the 21st century. The researchers used 30 secluded consecration projects from the UK to be examined; as per the findings, it can be observed that one payment was late in more than 70% of the residential projects. Furthermore, the study found that in more than 46% of the projects, contractors got their payments after the due date; while, in 56% of the projects, contractor's payments were late.

3.6 Theme 6: Moving towards a more sustainable construction business practises to focus on green future:

By 2030, there will be 8.5 billion people on the earth, due to the rapid increase in population (Umar, 2020). The sustainability of the planet depends on protecting our non-renewable resources, and sustainable building practises do just that. Both public and private developers can use green building techniques to address environmental issues. It has been found that the construction industry in the UK alone generates more than 222.2m tonnes of construction waste back in 2018, which was 120 million tonnes in 2016 (Ghaffar, Burman and Braimah,2020). In addition, the author states that the industry contributes to more than 40% of the overall CO_2 emissions. Therefore, contractors and clients must work jointly to design and develop new frameworks that decrease carbon footprint.

4. Discussion, Conclusion and Recommendations

The effectiveness of clients and contractors' relationships in the IPC is crucial in meeting contractual agreements and obligations. The contractors oversee creating structural and architectural designs, purchasing building supplies, planning construction sequences, and carrying out works on site in accordance with the approved blueprints (Newman *et al*. 2020). Therefore, it is the responsibility of both clients and contractors, as derived by the JCT standard form of contract, to ensure whether all the IPC norms are being followed or not and that's one of the benefits of JCT to encourage the collaboration and coordination between stakeholders by setting the liability on both. However, this study highlighted that for many construction projects, there are trust issues that deteriorate the effectiveness of the on-going projects. The findings of the study highlight the importance of the IPC system, as it enables contractors to collect all types of payments and thereby valuing project works and progress. It has been found that interim payments offer a clear and meaningful mechanism for clients and contractors prior to completion of projects. The Construction and Regeneration Act and the Housing Grants in the UK highlight that any party to a construction contract more than more than 45 days is entitled to stage as well as interim payments (Bralić, 2019). Although interim payments are frequent monthly payments whose value is determined by the value of work that has been accomplished, interim payments can also be agreed upon in advance and paid at specific milestones. These payments are recorded on an interim certificate, which the client is required to honour within the contract's allotted timeframe. The interim certificate is often appraised by cost consultants after consulting the lead designer and customers must notify contractors of their intended payment amount.

Improper arrangements of the IPC such as lack of management/supervision, un skilled Quantity surveyors to valuate, lack of transparency and traceability of work progress, low quality inspection system, poor controlled quantity measurements system in line with contractual methods of measurement, in addition to unclear payment terms and contractual obligations, can lead to issues related to productivity of contractors and workforce which consequently would impact the overall success of construction projects, not only in terms of quality but also time in terms of delay, and cost aspect in terms of extra costs and less profitability. Consequently, clients will not get best value of money and disputes would take place and that's what the research aims to mitigate.

The results indicate that the IPC issue is not only impacting specific group of contractors or clients, but it is a global concern. However, managers and quantity surveyors with the required skills and knowledge can lead and reduce the issues related to payment systems. Using BIM as a tool to enhance transparency and traceability for quantities and materials, and to have one model graphically representing the contractual obligations and progress for all stakeholders are also helpful. In addition, for fast payments in terms of transferring, tracking, low cost and transparent transactions, Block chain is taking the lead to fix such issues. In case the payment is done in a confidential and transparent manner more investors will be attracted to invest within the construction companies.

An IPC system with appropriate tools, it can play a positive role in the profitability of constructors. When profitability is increased, such companies can offer higher benefits to lower supply chain partners. Therefore, the relationship between workers and contracting companies will be improved. If contracting companies finish projects on planned deadlines, it can leave a good impression on consumers and allow clients get the best value for money. Consequently, fewer disputes would arise related to late payments or contradiction between payment application values from contractors and client certified values.

Various issues have been observed related to this subject that reduce the effectiveness of the IPC and open the door for future research, which include:

- It is required that payments are only provided by professional engineers; therefore, it is recommended to skill up graduates so that the requirements of potential engineers are fulfilled.
- Construction entities with good management facilities have faced less IPC-related issues than the other companies; it is possible only because of the experienced managers working for these companies. When construction companies give major priority to obtaining experienced managers with suitable know-how, the risks related to IPC will be drastically reduced.
- IPC must clearly show the total amount of retentions for nominated sub-contractors and any other potential deductions mentioned in the contract agreements and payment condition terms.
- In addition to the enhancement of the IPC system, contractors should work jointly with clients to agree on timelines, payment terms and breakdowns of activities, quality inspection system, progress quantity justification process and payments compared to expected cash flows to provide better value of money beneficial for both parties.

From the authors point of view, it is essential to focus on the role of BIM in IPC systems; BIM enables stakeholders to evaluate various potential project impacts even before construction starts by including specific building materials and information into the early design stages, especially when it comes to resolving disputes before, during and after construction, with higher quality, increased production, accuracy, transparency by let all stakeholders dealing with one model and time/cost savings as the end results.

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Material Passports for the End-of-Life Stage of Buildings: A Systematic Review of Benefits & Challenges

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Abstract

In many parts of the world, the construction industry is dominated by a linear economy, in which "take-make-waste" generates an alarming amount of construction and demolition waste (CDW). On the other hand, circular economy advocates for reintroducing CDW into the material flow as secondary materials. To aid this practice, building material passports were introduced as a comprehensive information database for buildings that facilitate the distribution of information across all stakeholders of the project. In this paper, a systematic review of the literature surrounding material passport development was conducted. First, this paper presents a bibliometric analysis of the recent trends in material passport research and related topics. Second, circular economy practices that benefit from implementing material passports were identified and discussed. Third, the benefits and challenges of implementing material passports were also identified and categorized. These findings are insightful for circular economy practitioners interested in learning about the latest development in material passport research and its relation to other circular economy practices.

Keywords

Material passports, circular economy, end-of-life, building construction, material re-use, construction & demolition waste management

1. Introduction

The construction industry is one of the major sectors that contribute to global energy use and waste production. The current construction practices worldwide support an unsustainable development path for the global economy. According to United Nations records, the global urbanization rate has reached 55% in 2019 and is expected to reach 68% by the year 2050 according to Aslam et al. (2020), which means a huge amount of construction projects will take place, hence more waste generation by the end of life of these projects. In 2017, the amount of waste due to construction and demolition in the US alone was estimated as 569 million tons based on Aslam et al. (2020), which shows how critical the construction waste issue and the urgent need for a strategy to manage the generated waste. CDW have significant impacts on the environment. In fact, this type of waste is either disposed in landfills or by incineration. Disposal by landfill only serves as short-term solution of CDW, as landfill negatively impact the soil it covers and space will run out eventually (Chen et al., 2021). In addition, the existence of this waste in landfills contributes to land and air pollution. It can also contaminate ground and surface water as toxic chemicals transfer through leachate (Chen et al., 2021).

The amount of extracted raw and natural resources used in construction projects is significant, and building materials at the end-of-life (EoL) stage are more likely to get disposed rather than recycled or reused (Benachio et al., 2020). Circular economy (CE) aims to keep materials and products circulating in the economy through reuse, remanufacturing, and recycling after buildings reach the EoL stage. However, the concept is not widely adopted in the industry. Material passports (MP) are an information management tool developed to boost recycling potential, enhance material recovery, and optimize the design process as cited by Soman et al. (2022). This paper reviews the recent literature on material passports, their role in facilitating circular economy practices, and their benefits and challenges. Use fewer primary resources, maintain the highest value of materials and products, and change utilization patterns.

Materials used in construction are usually tracked and verified until they are installed. After becoming part of a building, the tracking of materials is considered unnecessary, as their primary use has been fulfilled. A material passport is a digital comprehensive database for all building material information of a specific building that gives the materials of a building traceable identities (Honic et al., 2019). By giving the material an identity, MPs allow a shift in mindset towards CDW as secondary building materials rather than disposable waste, thus creating a market for re-use and an incentive for suppliers to manufacture sustainable and resilient material. Most importantly, MPs facilitate circular economy practices at the end-of-life stage of the building (Munaro et al., 2019).

Material passports are one of the sustainable development tools that promote the reuse and recycling of building materials and achieve circular economy instead of the take-make-waste system. A material passport is a digital data set that shows all the components and materials used in a built structure as explained by (Benachio et al., 2020). Using material passports by the end of life of buildings makes it easier to recovering materials instead of disposal. In addition, the value of a building material is preserved throughout the project's lifecycle and the potential of reusing or recycling it is increased. This can also eliminate any costs associated to the transportation and production of new building material, and material passports exist in different types; excel sheets are example of material passports. It can also be in the shape of online platform or a 3-D detailed model that shows all materials in a certain building (Soman et al., 2022). Moreover, material passports contain different types of material information in a high level of detail. This helps clients to have a clearer view of what a building consists of in terms of the economic and environmental values. Furthermore, some of the information listed in a material passport are place of origin, market price, supplier, after-construction condition, and the environmental impact (Soman et al., 2022).

2. Methodology

Three research questions were formulated for this review, and qualitative secondary data from peer-reviewed journal articles were used to answer them. The research questions were as follows: (1) "How do material passports facilitate circular economy practices at the end-of life stage of buildings?", (2) "What are the benefits of implementing material passports in the construction industry?", and (3) "What are the challenges involved in adopting material passports in the construction industry?" The screening process was limited to Scopus, due to its compatible with VOS viewer. The search was limited to scholarly sources published in English between 2015 and 2022. Selecting the articles involved a 4-step filtering process, illustrated in Figure 1. First, the keyword combinations used were "building construction AND circular economy", "building construction AND material passport", and "building construction AND material stocks". A total of 109 articles were found. Second, 6 duplicates were removed. Third, the remaining articles underwent abstract screening to eliminate articles not within the scope of this review, narrowing it down to 52 articles. Finally, in-depth reading was conducted based on the content of the articles. After this step, the number of articles remaining was 37 articles. Regarding the bibliometric analysis, VOS viewer was used to identify the trends in publication rate, keyword co-occurrence, and leading countries in material passport research. Afterwards, a discussion of the reviewed papers is presented, where the benefits and challenges are discussed and categorized.

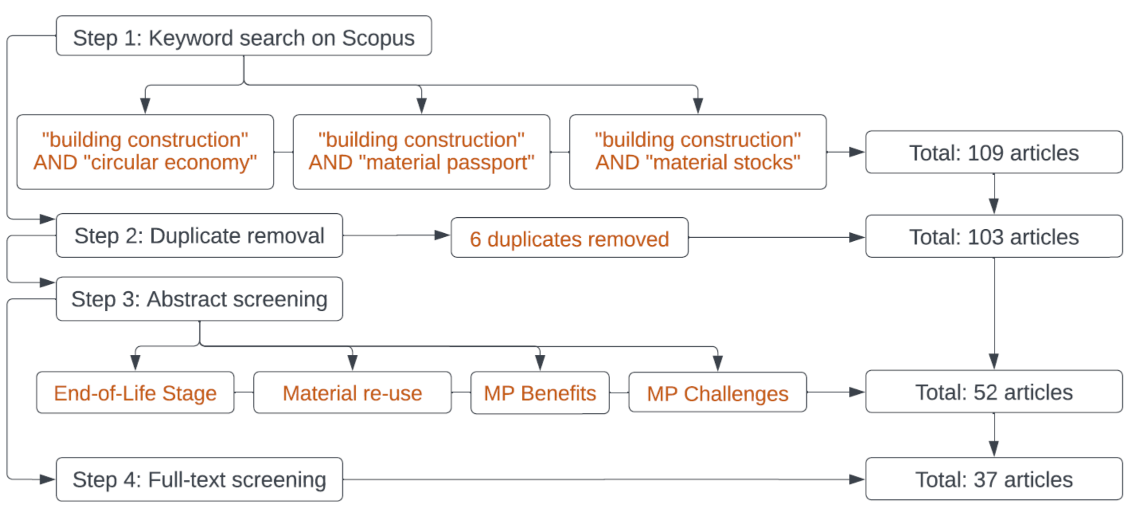

Fig. 1. Article selection process

3. Results

This section presents the results of the bibliometric analysis, which was the first step to answering the first research question.

Fig. 2(a) shows the leading publishing countries represented in the bibliometric network. Austria leads in publications for material passports, followed by the United Kingdom, Netherlands, and Spain. Fig. 2(b) illustrates the distribution of the most frequently used keywords over 97 articles in the bibliometric network. The top 5 keywords identified from the literature were: circular economy, building construction, construction industry, sustainable development, and environmental impact. The newest trends were in: demolition, planning, economic analysis, and material flow analysis.

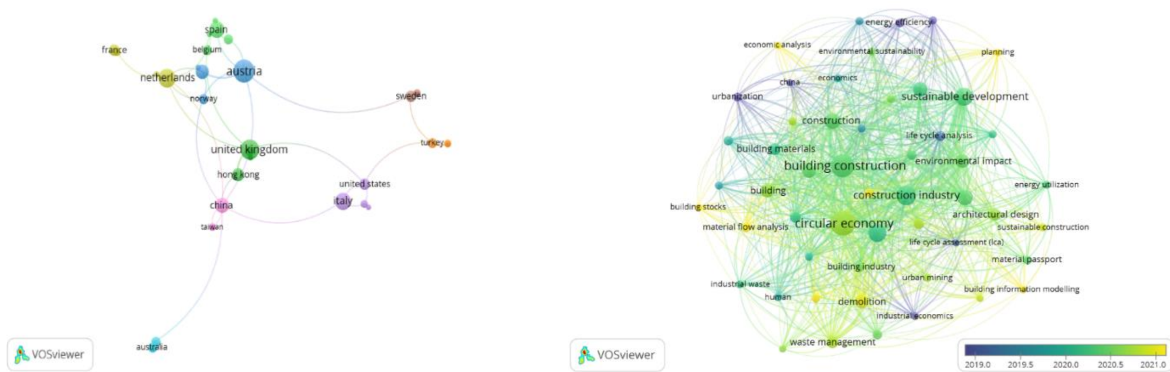

Fig. 2. (a) Bibliometric network of the countries, (b) Bibliometric network of the keyword

Fig. 3 shows the number of published articles over the past 7 years from 2015 to 2022. From 2015 to 2018, the number of published articles did not exceed 5 publications per year. However, the graph shows significant growth since 2018 and is likely to continue increasing in terms of the number of publications.

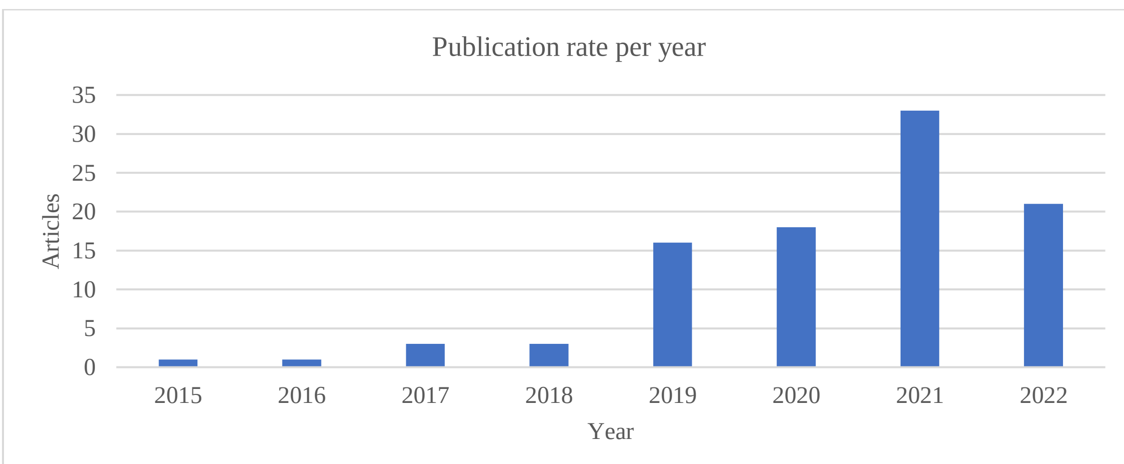

Fig. 3. Bar chart of publication rate per year for material passports

In Table 1, the previous literature was reviewed and categorized according to three main CE practices at the EoL stage.

Table 1. Thematic analysis of keywords

Theme	Articles	Total
Material Passports	(Caldas et al., 2022; Oluleye et al., 2022; Pronk et al., 2022; González et al., 2021; O'Grady et al., 2021; Rakhsan et al. 2020; Augiseau & Kim., 2021; Bertin et al., 2020; Nordby, 2019; Smeets et al., 2019; Hopkinson et al., 2019; Çetin et al., 2022; Zhang et al., 2021; Honic et al., 2021; Rahla et al., 2021; Li & Wang, 2021; Talla & Mcllwaine, 2022; Çetin et al., 2021; Almusaed et al., 2020; Schützenhofer et al., 2020; Kovacic et al., 2020; Honic et al., 2019c)	22

Material Re-use	(Munaro et al., 2019; Caldas et al., 2022; Smeets et al., 2019; Munaro & Tavares, 2021; Honic et al., 2019b; Atta et al., 2021; Çetin et al., 2022; Zhang et al., 2021; Honic et al., 2021; Rahla et al., 2021; Li & Wang, 2021; Talla & Mcllwaine, 2022; Kovacic & Honic, 2021; Çetin et al., 2021; Almusaed et al., 2020; Heisel & Rau-Oberhuber, 2020; Schützenhofer et al., 2020; Kovacic et al., 2020; Honic et al., 2019c)	18
Material Stocks	(Çetin et al., 2022; Talla & Mcllwaine, 2022; Kovacic & Honic, 2021; Çetin et al., 2021; Almusaed et al., 2020; Heisel & Rau-Oberhuber, 2020; Kovacic et al., 2020; Honic et al., 2019c)	8

4. Discussion

The following section will discuss the circular economy (CE) strategies for materials of buildings at the EoL stage, and how material passports (MPs) aid in enabling these strategies. Next, the benefits and challenges of MPs are presented.

4.1 CE practices at the EoL stage

The EoL stage of buildings is when they outlive their useful lifespans and are typically scheduled for demolition to make way for new developments. To close the material loop, Giorgi et al. (2018) define two strategies for reclaiming materials of buildings at the EoL stage: (1) Increasing the materials' lifespan through reuse, recovery, or remanufacturing, or (2) Transforming the materials into new products through recycling. The strategy chosen largely depends on the quality of salvageable materials and the purpose behind collecting that material. Oluleye et al. (2022) state that direct material reuse should be the first strategy considered, as it requires the least energy consumption, carbon emission and cost. They emphasize that this strategy is suitable for materials that preserved their high quality at the EoL stage. Recovery and recycling fulfill the same purpose of reprocessing materials into new products, but they differ in their processing method (Oluleye et al., 2022). Remanufacturing is the least used method globally, left for when other strategies are not sufficient (Oluleye et al., 2022).

Material reuse is the strategy with the lowest carbon footprint among the circular economy practices; however, there exists an unwillingness among construction stakeholders to adopt it. Adopting the material reuse strategy requires the involvement of all stakeholders in the material value chain and a thorough understanding of circular thinking in construction (Pronk et al., 2022). According to Rakhshan et al. (2020), one reason behind their uncertainty arises from the perceived high risk involved. Compliance to existing regulations and concern over health and safety are among the risks mentioned by Rakhshan et al. (2020). Thus, certain pre-requisites must be met to enable the material reuse market. The authors suggested developing standard test procedures to evaluate and certify the secondary material to improve stakeholders' perception by offering quality products. Moreover, they encouraged adopting design-for-deconstruction and training workers for deconstruction skills. Lastly, they identified the need for cheap and reliable techniques to evaluate reusability to streamline the process of certifying secondary materials.

In response, another study proposed a method to evaluate material reusability called the design for disassembly, deconstruction, and resilience index (O'Grady et al., 2021). The authors defined *deconstruction* as the removal of a building's structural elements; *disassembly* as to the removal of non-structural elements, such as wall cladding, flooring, and internal finishes; and *resilience* as the condition of reclaimed materials after being dismantled and relocated (O'Grady et al., 2021). Quality is a major concern for stakeholders when discussing material reuse, so this reusability measurement tool is a step in the right direction towards standardizing the material reuse market (O'Grady et al., 2021).

Along with measurement tools, there is a need for better documentation that can facilitate material reuse negotiations between stakeholders. The aim of a material passport is to document the material composition of a building, and this practice can improve the visibility of reusable materials in existing buildings before they are demolished. One major regional effort towards this goal was accomplished by the Buildings as Material Banks (BAMB) project, which was funded by the European Union. Spanning between 2015 and 2020, the BAMB project aimed to develop a digital platform for material passports. The project was a collaborated effort between companies, institutes, and universities located in 8 countries to create over 400 passports (i.e., 345 product passports, 7 building passports, and 76 instance passports) (Luscuere et al., 2019). A product passport includes information about a product from a manufacturer, a building passport is made up of product passports and building-specific information, and an instance passport provided more detailed information about a specific instance of a product (e.g., a specific door in a building is an instance of the generic Door product) (Luscuere et al., 2019).

In a BAMB report written by Heinrich and Lang (2019), the material passport prototype included 11 information sections: (1) Physical properties, (2) Chemical properties, (3) Biological properties, (4) Material health, (5) Unique product and system identifier, (6) Production data, (7) Location within the building, (8) Transportation, (9) Use and operation, (10) Disassembly/Reversibility, (11) Reuse and recycle. The authors identified that formatting differences may hinder efforts to create machine readable data, to introduce new users to MPs, and to standardize MPs on a wider scale. Thus, the next step is to standardize the material passport format and content needs.

Material stock analysis, like material passports, is a valuable source of information to visualize the available material stock in an area. A material stock is the sum of products, buildings, and infrastructure that stay within the economy for at least a year. The value of the material stock is in its reusability, how reliably it can be deconstructed and stored, and when it will be available in the market. Material stock analysis refers to information on location, quantity, quality, and others represented as a map of material available within a certain area (e.g., city wide, country-wide). Benachio et al. (2020) conducted a review of material stocks literature and found that city-wide assessment of material stocks based on existing buildings is possible and can benefit from further development to improve information reliability in the long term.

4.2 Benefits of Material Passports

As part of a circular economy approach at the end of life, the implementation of material passports technique in construction projects can derive various benefits. The benefits obtained from the literature are mainly categorized as environmental, social, and economic. In the long-term, the utilization of material passports promotes the reuse and recycling of construction materials and building components by the end of their lifecycle. In the short-term, material passports can provide the relevant information on various aspects of the building project to different stakeholders throughout the project life. This efficient access to information can reduce the expensive deconstruction mistakes and construction schedules (Blengini, 2009). Moreover, it can also ease the cooperation between stakeholders and increase the traceability of materials used in a certain project. In addition, it can potentially preserve or increase the value of building components as reusable or recyclable material by the EoL stage (Blengini, 2009). This can also reduce CDW which saves costs and reduces harm on environment.

First, in terms of the environmental impact, it was found out that the integration of circular economy practices by the end of life of construction projects reduces the demand on natural and raw resources. It also eliminates the long haulage process of the new resources from their origin to factories (Silva et al., 2019). This saves huge amounts of CO_2 emissions which is eventually beneficial to the environment. In addition, according to Minunno et al., a modular purpose-built prototype was designed and built-in order to assess the environmental benefits of reusing materials (2020). The project under the name of Legacy Living Lab (L3) was designed for disassembly by the EoL stage. The purpose of material passports utilization is to provide a wide understanding about how the materials can resulted from disassembly be recycled or reused in order to be used in a new building. The L3 project has undergone a lifecycle assessment in order to define what environmental benefits it has brought. It was found out that the implementation of a circular economy practice at the end of life saved around 87% of the total embodied energy (Minunno et al., 2020). In other words, if the L3 was built as a linear model it would have resulted in 5460 megajoules (MJ) embodied energy. However, since the model was built as a CE it has only embodied around 750 MJ. In addition, the circular L3 has shown a significant decrease in the global warming potential. This reduction was estimated at around 28% when compared to the global warming potential resulting from conventional or linear models (Minunno et al., 2020). In addition, the proper management of buildings' components at the end of life avoids landfilling the demolished waste. This will result in providing more capacities in landfills and reducing the demand on waste dumps, and hence saving more land areas. This achieves sustainability goals since land has become a scarce source and has to be preserved.

Second, the use of circular economy practices at the end of life of construction projects can be economically beneficial. This is because it can save huge amounts of costs that are mainly wasted upon eliminating the danger of collected waste that impacts human health (Marzouk et al., 2014). For example, a simulation was designed in Egypt in 2014 in order to predict the difference in waste amounts in case circular economy practices are adopted at the end of life of projects. It was found out that the adoption of circular economy practices can eliminate costs that are incurred by the government annually (Marzouk et al., 2014). These costs are mainly associated with the expenses of mitigating the damage caused by emissions and air pollution which are resulted from demolition waste and impacts human health, costs of reducing the harm of collected waste that impacts the surrounding environment, and costs that are spent on designing and building new landfills and waste dumps (Marzouk et al., 2014). According to the simulation, the proposed cost eliminations are significant. For example, in Egypt, the unit cost of constructing small, medium, and large landfills is 165.58 $\$/m^3$, 99.29 $\$/m^3$, 66.29 and $\$/m^3$, respectively. In addition, costs required to mitigate air and land pollution are estimated as $16,161.35 billion over a period of 20 years (Marzouk et al., 2014). In fact, the integration of circular economy practices at end of life which involves reusing and recycling materials would eliminate most of the listed costs and disburden these amounts from the government. This proves the importance of financial benefits of the circular economy.

Third, social benefits can also be obtained through the implementation of material passports. The social aspect shares the same importance with the economic and environmental profile of circular economy since it is one of the sustainability pillars. The paradigm shifts into sustainable systems that was proposed by several studies involves the reduction of impact on human health (Minunno et al., 2020) and (Marzouk et al., 2014). In fact, the conventional approach to manage buildings' materials and components by the end of life imposes high risk on human health. The utilization of material passports which encourages the reuse of materials is an enabler to control the rising amounts of pollution and waste that impacts air and land and eventually threatens human welfare and wellbeing (Wijkman et al., 2015). In addition, it is expected that the extensive transition to circular economy practices can provide new jobs in the market and reduce unemployment rates. This is because practitioners have to be well prepared and trained to deal with technologies such as material passports (Wijkman et al., 2015).

Table 2 summarizes the thematic analysis of the benefits identified from the literature; the benefits are categorized into three categories based on the sustainability pillars as mentioned in literature. It is clearly indicated that most of the studies focused on the environmental benefits of MP and very few highlighted the social benefits on human health and well-being.

Table 2. Thematic Distribution of MP Benefits

Category	Article	Total
Environmental	(Benachio et al., 2020; Blengini, 2009; Silva et al., 2019; Marzouk et al., 2014; Li & Wang, 2021)	6
Economic	(Silva et al., 2019; Marzouk et al., 2014; Li & Wang, 2021)	3
Social	(Silva et al., 2019; Wijkman et al., 2015)	2

4.3 Challenges of Material Passports

Technical challenges in implementing material passports were highlighted in several studies (Nordby, 2019; Munaro & Tavares, 2021; Çetin et al., 2022; Zhang et al., 2021). Nordby (2019) stated that the technical, is due to deficiency of information about used construction materials that will be likely to attain in other project, which makes this practice not effectual to be executed. Additionally, Honic et al (2021) highlights the same issue while integrating building information modelling (BIM) and MP. Another study by Çetin et al. (2022) highlighted the challenges of implementing material passport, based on interviews conducted with experts, revealed that MP challenges are technological, regulatory and market challenges. Technological challenges were also presented, such as lack of data management mechanisms, high costs of implementing digital technologies into material passport practice, and lack of technological integration. Lack of data management mechanisms; in the sense that this material might last for 50-80 years, considering the lifetimes of the material (Zhang et al., 2021), such as foamed concrete 50 years, exterior wall paint 35 years, and mortar 75 years, which necessitates the material information in the passport is dynamic to reflect the status of the material over time. High costs of implementing digital technologies into material passport practice, since implementing material passport will require a lot of technology adoption into the field, which will be expensive. Lack of technological integration; in which to have an effective material passport implementation, we should integrate the practice with technology tool, such as building information modelling (BIM), however, the lag of this integration is causing MP to be impractical. Moreover, the volume of data generated from MP is enormous, in which each material embedded in a building should be fully described, this huge amount of data needs to be stored safely for a long period of time, which makes this a serious challenge (Munaro & Tavares, 2021).

Market challenges are defined by the lack of viable business models. Practical models for MPs exist; however, they are not fully automated to update over time, resulting in outdated data (Çetin et al., 2022). Additionally, Nordby (2019) calls it an undeveloped market, as it will be a challenge for professional practice to execute, due to the lack economic driving influence. Due to added time required for engineering and demolition, uncertainty around documentation, and additional expense, a construction process using reused materials becomes complicated and expensive.

The regulatory challenge is due to the lack of regulations and framework for selling and utilizing used materials in in new building; also referred to as organizational challenge (Nordby, 2019). Additionally, Almusaed et al. (2021) emphasized on the fact that the lack of technical regulations is one of the most contributing barriers. Another study defines the regulatory challenge, is the lack of regulations for material reuse in terms of standards that encourage the reuse practice (Çetin et al., 2022; Sigrid Nordby, 2019).

The political challenges are divided into four main categories based on Munaro & Tavares (2021) and Munaro et al., (2019), including the complexity and fragmentation of the construction supply chain, causing an increase of material waste and cost of projects, and risk the project due date. The second challenge is conflicting environmental and energy policy measures; in which if we prioritized high-energy performance buildings, this would encourage the usage of materials that are not suitable to deconstruction and reuse. Furthermore, lack of standardizing project data, in which identifying the reuse potential materials might be impossible since not enough data is provided. Additionally, the lack of certification and quality assurance for recycled materials is also a political challenge.cc

Since MPs are presented in different levels, starting from broader to more specific, building, system, component, and material (Zhang et al., 2021), identifying and separating materials and products to maintain quality is a challenge. Studies by Munaro & Tavares (2021) and Munaro et al. (2019) refer to it by complexity of materials/ systems/ components. Additionally, longevity of buildings and infrastructures is another commercial challenge in which there is a different lifecycles and maintenance required for buildings, and the components, for this specific information should be highlighted in the MP. Moreover, suppliers usually refuse to provide information that would expose their business, creating another challenge to collect data required in the material passport. Munaro & Tavares (2021) and Munaro et al. (2019) refer to this challenge as intellectual property concerns. Not only suppliers might cause a challenge in implementing MP practice, but also stakeholders might, in which their commitment is very essential to providing reliable data for material to be reused. This challenge is also indicated as collection and release of reliable data, and after getting this data it should be continually updated and should present the current state of materials embedded. Thus, constant data and information updating is also a challenge (Munaro et al., 2019; Munaro & Tavares, 2021). Studies have highlighted the importance of stakeholder's engagement implementing MP practice. Smeets et al. (2019) believe that MPs cannot be fully utilized without the stakeholder's engagement. Similarly, Rahla et al. (2021) believe that stakeholder involvement is one of the barriers hindering the adoption of MP, since when stakeholders monitor, identify, and assess material, more quality assurance will take place of recycled materials to match supply with demand. The incorporation of sensors into materials is the last challenge, in which plugging sensors in the material, will provide the current state of it and real-time data, which can also be a challenge to execute (Munaro & Tavares, 2021; Munaro et al., 2019).

Finally, the social challenges are divided into three sub-categories based on Munaro & Tavares (2021)and Munaro et al. (2019). Reversible design can reduce long-term costs; however, it requires a high capital cost. For that, estimated savings in reversible design is inaccurate, which is considered a social challenge hindering the adoption of MP practice. Another challenge is that people are not aware of flexible buildings and the concept is not well known, due to the lack of protocols for owners and users. Finally, the existence of other construction practices is prioritized, such as safety and energy efficiency.

Table 3 summarizes the thematic analysis of the MP challenges discussed above.

Table 3. Thematic analysis of MP challenges

Category	Details / Subcategories	Sources
Technical	• The lack of data management mechanisms • Lack of technological integration • Deficiency of information about used construction materials • The lack of storage network	(Nordby, 2019; Munaro & Tavares, 2021; Çetin et al., 2022; Zhang et al., 2021; Honic et al., 2021)
Market	• Lack of viable business model • Undeveloped market • Lack of economic driving influence	(Nordby, 2019; Çetin et al., 2022)
Regulatory	• Lack of framework for selling and utilizing used materials • Lack of technical regulations • Lack of standards for material reuse	(Nordby, 2019; Çetin et al., 2022; Rahla et al., 2021)

Political	• Complexity and fragmentation of the construction supply chain • Conflicting environmental and energy policy measures • Lack of standardized project data • Lack of certification and quality assurance for recycled materials	(Munaro et al., 2019; Munaro & Tavares, 2021)
Commercial	• Complexity of material and systems in the construction industry • Longevity of buildings and infrastructures • Intellectual property of materials • Lack of stakeholder's engagement	(Munaro et al., 2019; Smeets et al., 2019; Munaro & Tavares, 2021; Li & Wang, 2021)
Social	• High initial capital cost • Lack of awareness, stakeholder hesitation • Lack of priority	(Munaro et al., 2019; Munaro & Tavares, 2021)

5. Conclusions

The increasing rates of urbanization and building demolition create significant amounts of waste that have long-lasting effects on the environment. To answer this review's research questions, qualitative secondary data from peer-reviewed journal articles were extracted using the Scopus database. Four circular economy practices were identified for the end-of-life stage of construction projects facilitated by the use of material passports. In addition, the benefits and challenges of implementing material passports in the construction industry were investigated. The unique value of this review paper is its focus on the EoL stage, whereas previous review papers focused on the CE practices at the design and construction stages. Moreover, the development of material passports received new advancements in recent years that had not been reviewed. Subsequent paragraphs, however, are indented (here insert the second paragraph).

The four main CE strategies for handling CDW are reuse, recycling, remanufacturing, and recovery. Reuse requires the least energy consumption, carbon footprint and cost, but there is a prevalent unwillingness among stakeholders to adopt this practice. However, efforts have been made in recent years to combat the stigma associated with reusing building materials, and the prerequisites for it were discussed. The implementation of material passports has indirect positive impacts on the environment, economy, and society. Significant reduction to CO_2 emissions, reduced demand on raw materials, and reduced demand for landfills are among the top environmental incentives. Moreover, major cost reductions can be achieved from using secondary building materials. From a social perspective, the benefits included reducing the impact of pollution on human health and creating new jobs related to material passport development and extending the material supply chain to the material reuse market. Challenges extracted from literature were categorized into technical, market, regulatory, political, commercial, and social. The technical challenges were the main focus of previous studies, but these challenges stem from a general lack of priority or engagement of construction stakeholders who are not familiar with circular economy practices.

Lastly, the research gaps should be mentioned for future researchers to consider. The current state of the literature showed more concern for the challenges rather than the benefits, which reflect that material passports are still in the early stages of maturity in circular construction research. For future work, more implementation studies are needed to continue experimenting with material passports and their usability. Subsequently, the social benefits may become more apparent with more implementation studies carried out. Similarly, a closer look at the challenges is warranted to understand the milestones needed to overcome them. One of these milestones that could be explored is finding the means to measure the circularity of building materials. Overall, these findings are insightful for circular economy practitioners interested in learning about the latest development in material passport research and its relation to other circular economy practices.

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Incorporating Safety in Construction Contracts- The Experience from the Construction Industry of Pakistan

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Abstract

Construction accidents and the associated damage they cause to employees, property, equipment, and morale have generated negative effects on the industry's profitability and productivity. One of several approaches to help address the poor safety performance is to hold the contracting parties 'contractually responsible' for their safety performance. The purpose of this study is to assess local industry awareness and perceptions of relevant contractual provisions in Pakistan. The intent is to identify practices and procedures currently used in the industry to fulfill the safety requirements in the contract documentation. Another objective is to benchmark the importance, usage, and effectiveness of selected contractual provisions that have the potential to help improve construction safety scenario in the local construction industry. After referring to national and international contract guidelines, a questionnaire was developed with selected safety clauses that will help accomplish the stated objectives. Local construction contractors were approached for the questionnaire survey. The gathered data was analyzed via descriptive and inferential statistical techniques. The data analysis led to the conclusion that, according to a majority of respondents, up to 10% of a company's contract disputes are related to construction safety; at a cost of up to 20% of contract value for resolution. Safety training is normally prescribed in the contracts, and written contractor safety programs are required. Most of the respondents were of the view that safety training should be made compulsory. However, an overall feeling amongst the respondents about the current state of "safety incorporation" in contracts in Pakistan's construction sector is 'poor'.

Keywords

Construction Accidents, Contractual Safety Provisions, Developing Country

1. Introduction

Due to its distinctive characteristics, unexpected site circumstances, variety of human behavior, and risky processes, the construction business has high rates of fatalities and injuries (Ho et al., 2000). The same notion is also corroborated by the data for wounded workers from Noman et al., (2021). The values represent the percentage of total employed persons suffering occupational injuries in the respective industry sector. Refer to Table 1 below.

Table 1: Index-based industry divisions of injured workers in Pakistan. (Source: Noman et al., (2021))

Industry Sectors	2001-02	2003-04	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2012-13	2013-14	2014-15	2017-18
Manufacturing	14.5	14.61	17.1	15.21	12.72	13.96	12.8	15.8	13.32	14.2	15.9	16.9
Construction	12.54	10.65	13.21	14.55	14.93	14.54	14.25	13	15.24	14.1	16.3	17.3
All Others Combined	10.42	10.68	9.95	10.03	10.31	10.21	10.42	10.17	10.22	10.24	9.69	9.40

A study in Pakistan found that the major injuries experienced by contracting firms on their project sites, as reported by the survey respondents, are listed below, in order of decreasing frequency (the percentages in parenthesis indicate the weighted average percentages of the injuries based on a combined proportion of the percentage of the injury's occurrence and percentage of companies facing the injury). 1. Injury from falls (55%) 2. Accidental injuries (53%) 3. Raw material and waste-related injuries (36%) 4. Heat illness (33%). 5. Head trauma (25%) 6. Injury to the eyes (6%) 7. Cases of burning (9%) Farooqui et al., (2007).

According to most of the contractors surveyed in a study by Farooqui et al. (2007), developing safety policies and manuals (69%), including general safety guidelines in the body of the contract (64%), establishing physical controls and rules (61%), and integrating safety into project schedules are the mechanisms that best contribute to implementing and improving safety on projects. Zahoor et al. (2016) also support the notion of addressing construction safety and assert that Occupational Safety and Health training is the most overlooked component among the causes of poor safety performance, followed by the omission of safety from contracts.

One of the primary issues with construction safety is the lack of unambiguous contractual safety responsibilities. Assigning appropriate contractual safety obligations prior to contract execution is therefore in the best interest of all project participants. Abdul Nabi et al., (2020). The overall safety performance of projects will improve with the clear assignment of safety obligations in contracts, which will also reduce claims, disagreements, and disputes linked to safety injuries in the construction industry. Abdul Nabi et al., (2020). In fact, one of the four frequently occurring reasons for claims in the construction business is safety-related difficulties (LaBarre and El-adaway 2014).

This research attempts to benchmark the perception of the local construction industry regarding the importance; usage and effectiveness of contractual safety provisions as a means to improve construction safety scenario in the local industry.

2. Literature Review

It cannot be stressed enough that it is in the best interest of all project participants to assign appropriate contractual safety duties and rights before the contract is executed. To reduce safety-related conflicts, claims, and disputes, precise contractual wording and effective contract management methods are essential Abdul Nabi et al,. (2020).

The Pakistan Engineering Council (PEC) is the mandated professional organization that sets the regulations for engineering projects in the country. It has incorporated the following OH&S clauses in its contract documents (cited from Zahoor et al., 2015).

a. Safety, security, and protection of the environment: It is clause 19.1 of Part-I (General conditions of contract) of PEC standard form of bidding documents (PEC, 2007, p.90).
b. Safety precautions: It is clause 19.3 of part-II (Particular conditions of contract) of the PEC standard form of bidding documents (PEC, 2007, p.152).

The PEC documents include safety in the following manner:

- Health and safety: Due precautions shall be taken by the contractor, and at his own cost, to ensure the safety of his staff and labor at all times throughout the period of the contract. The contractor shall further ensure that suitable arrangements are made for the prevention of epidemics and for all necessary welfare and hygiene requirements.
- Records of safety and health: The contractor shall maintain such records and make such reports concerning the safety, health, and welfare of persons and damages to property as the Engineer may from time to time prescribe.
- Employer's responsibilities: If under clause 31 the employer shall carry out work on the Site with his own workmen he shall, in respect of such work:
    a. Have full regard for the safety of all persons entitled to be upon the Site and
    b. Keep the site in an orderly state appropriate to the avoidance of danger to such persons.

  If under clause 31 the employer shall employ other contractors on the site, he shall require them to have the same regard for safety and avoidance of danger.
- Safety, security, and protection of the environment: The contractor shall, throughout the execution and completion of the works and the remedying of any defects therein:
    a. Have full regard for the safety of all persons entitled to be upon the site and keep the site (so far as the same is under control) and the works (so far as the same are not completed or occupied by the employer) in an orderly state appropriate to the avoidance of danger to such persons,
    b. Provide and maintain at his own cost all lights, guards, fencing, warning signs, and watching, when and where necessary or required by the engineer or by any duly constituted authority, for the protection of the works or for the safety and convenience of the public or others, and
    c. Take all reasonable steps to protect the environment on and off the site and to avoid damage or nuisance to persons or to property of the public or others resulting from pollution, noise, or other causes arising as a consequence of his methods of operation.

Similarly, for India, Sivaprakash and Kanchana's (2018) study presents an overview of the different statutory regulations for construction safety in India, with a focus on the BOCW Act, Central Rules, and State Rules. Provisions are given for overhead protection (rule 41), electrical hazards (rule 47), stability of structures (rule 49), test & periodical examination of lifting appliances (rule 56) and lifting gear (rule 70), operator's cabin (rule 63), transport and earth moving equipment (rule 88 to 95), concrete work (rule 96 to 107), demolition (rule 108 to 118), demolition of walls, partition, etc. (rule 110), inspection (rule 116), warnings signs and barricades (rule 117), mechanical method of demolition (rule 118), construction, repair & maintenance of steep roof (rule 169 – 171), ladders & step ladders (rule 172 to 174), catch platform & hoardings, chutes, safety belts & nets (rule 175 to 180), safety belt, safety net (rule 178 to 180), safety officer (rule 209), hazardous process (rule 225), notifiable occupational diseases (rule 230), hazardous processes (Schedule IX).

Ndekugri et al., (2022) argue that the New Engineering Contract (NEC) body of contracts, the conditions of the contract make only three specific references to H&S: the contractor's obligation under clauses 20.1 and 27.4 to act in accordance with the H&S requirements stated in the scope, the contractor's duty under clause 31.2 to show on each program submitted 'provisions for health and safety requirements' and contract termination provisions in clauses 90.1 and 91.3. Other related safety measures are addressed under clauses 91.1 and 91.3, Clause 10.2.

Fédération Internationale des Ingénieurs – Conseils or The International Federation of Consulting Engineers (FIDIC, 1987) addresses safety as follows:

- The contractor shall, throughout the execution and completion of the Works and the remedying of the defects therein:
    a. Have full regard for the safety of all persons entitled to be upon the Site and keep the Site (so far as the same is under his control) and the Works (so far as the same are not completed or occupied by the Employer) in an orderly state appropriate to the avoidance of danger to such persons,
    b. Provide and maintain at his own cost all the lights, guards, fencing, warning signs and watching when and where necessary or required by the Engineer or by any duly constituted authority, for the protection of the Works or for the safety and convenience of the public or others, and
    c. Take all reasonable steps to protect the environment on and off the Site and so avoid damage or nuisance to person or to property or the public or others resulting from pollution, noise or other causes arising as a consequence of his methods of operation.

Finally, the relevant safety provisions from the AIA Document A201 (2007) are as follows.

a. 3.3.1: "The Contractor shall be solely responsible for, and have control over, construction means, methods, techniques, sequences and procedures and for coordinating all portions of the Work under the Contract, unless the Contract Documents give other specific instructions concerning these matters. If the Contract Documents give specific instructions concerning construction means, methods, techniques, sequences, or procedures, the Contractor shall evaluate the job site safety thereof and, except as stated below, shall be fully and solely responsible for the job site safety of such means, methods, techniques, sequences or procedures. If the Contractor determines that such means, methods, techniques, sequences, or procedures may not be safe, the Contractor shall give timely written notice to the Owner and Architect and shall not proceed with that portion of the Work without further written instructions from the Architect."
b. 5.3: "… the Contractor shall require each Subcontractor… to assume toward the Contractor all the obligations and responsibilities, including the responsibility for safety of the Subcontractor's Work, which the Contractor… assumes toward the Owner and Architect."
c. 10.1: "The Contractor shall be responsible for initiating, maintaining and supervising all safety precautions and programs in connection with the performance of the Contract."
d. 10.2.1: "The Contractor shall take reasonable precautions for safety of, and shall provide reasonable protection to prevent damage, injury or loss to… employees on the Work and other persons who may be affected thereby."
e. 10.2.2: "The Contractor shall comply with and give notices required by applicable laws, statutes, ordinances, codes, rules and regulations, and lawful orders of public authorities bearing on safety of persons or property or their protection from damage, injury or loss."
f. 10.2.3: "The Contractor shall erect and maintain, as required by existing conditions and performance of the Contract, reasonable safeguards for safety and protection, including posting 14danger signs and other

warnings against hazards, promulgating safety regulations and notifying owners and users of adjacent sites and utilities."

3. Research Methodology

The methodology for this study is presented in Fig.1.

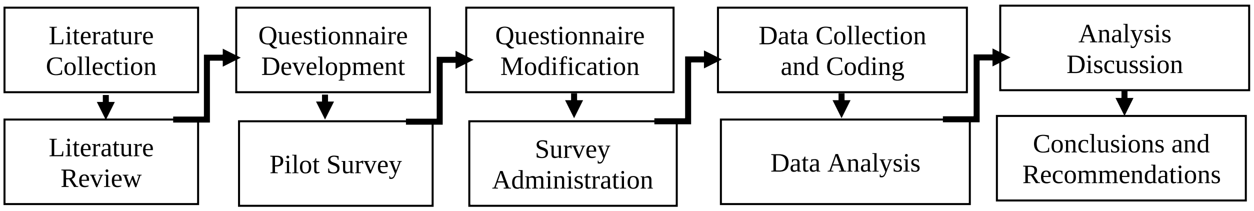

Fig.1. Research Methodology

Fig 1 is elaborated as follows:

- Literature Collection: The literature was collected using the keywords such as construction safety, contractual safety provisions, and construction safety performance of the local construction sector. In addition, model contract forms from PEC, FIDIC, AIA, and NEC were also consulted.
- Literature Review: Relevant portions of the collected secondary data were brought forward to extract literature that helped to establish existing safety provisions in model contracts, recent construction safety performance of local construction contractors, and also the importance of contractual safety provisions for improving the safety scenario in the local AEC sector.
- Questionnaire Development: The literature review process translated into the development of a questionnaire for the local industry stakeholders. Section 4 elaborates on the structure of the questionnaire in greater detail, especially in light of the data analysis and discussion.
- Pilot Survey: The pilot survey was administered to identify shortcomings in the survey instrument. The feedback received from the process was incorporated to improve it effectiveness and technical quality.
- Survey Administration: The survey administration was carried out using Google Forms and also via semi-structured interviews. The target audience was identified using personal contacts and also through graduate-level students studying at NED University of Engineering and Technology during Fall 2022. These students were part-time graduate students pursuing a higher degree in construction management. Their professional association was with local construction contractors, which made a suitable choice for survey respondents.
- Data Collection and Coding: The collected responses were recorded in MS Excel and all references to the respondent (if any) were deleted. The data analysis and respective figures and tables were generated using MS Excel. ANOVA analysis was carried out using RStudio.
- Data Analysis and Discussion: The data analysis and discussion are elaborated in Section 4.
- Conclusions and Recommendations: Pertinent conclusions and recommendations were drafted based on the insights obtained from data analysis.

4. Data Analysis and Discussion

The data analysis and discussion follow the structure of the survey instrument which had the following sections.

- Demographics of Survey Respondents.
- Questions to elicit information about the current status of contractual safety in the local construction industry
- Likert scale-based questions that required the respondents to rate the Importance (5=Not Important to 1=Very Important), Usage (5=Never Used to 1=Always Used), and Effectiveness (5=Not Effective to 1=Very Effective) respectively of selected contractual provisions that may help to improve the construction safety scenario in the local construction industry (refer Fig.1a and Fig 1b). A summary of descriptive statistics for the three analysis aspects of selected contractual provisions is presented in Table 2. The ranking of Selected Contractual Provisions is based on the three parameters (refer Table 3). Results of ANOVA analysis for the three aspects Importance, Usage, and Effectiveness respectively are presented in the following tables: Table 4 (One-way ANOVA for Usage~Importance Model); Table 5 (One-way ANOVA for Usage~Effectiveness Model); Table 6 (Two-way ANOVA for Usage~Importance+Effectiveness Model); Table 7 (Two-way ANOVA for Interaction Model); Table 8 (Performance of All Models and Selection of Best Fit Model). The last part of the questionnaire required the respondents to rate the significance (5=not at all significant to 1=

extremely significant) of barriers that impede the widespread adoption of contractual construction safety approaches in the local industry-Refer Fig 4.

4.1 Demographic Analysis

The demographic analysis of the survey respondents shows the following break up of experience and organizational positions.

- < 05 years (45%); 05-10 years (10%); 10-15 years (20%); > 20 years (05%); > 30 years (05%); > 40 years (10%); did not respond (05%).
- Owner/CEO (15%); Manager-Civil/PM (20%); Technical Advisor/Project Coordinator (10%); Planning Engineer (10%); Project Engineer/Site Engineer (45%).

4.2 Closed-Ended Questions' Analysis

The following summarizes the results of the close-ended questions as follows:

- Percentage of company's contract disputes related to safety issues [questionnaire option (percentage response)]: 0-20% (75%); 20-40% (20%); 40-60% (0%); 60-80% (0%); above 80% (5%)
- Time (%) spend on resolving contractual safety issue(s) [questionnaire option (percentage response)]: 0-10% (55%); 11-20% (25%); 21-30% (20%); above 30% (0%)
- Cost (% of Total contract value) incurred (on every project) resolving contract safety issues [questionnaire option (percentage response)]: 0-10% (35%); 11-20%(55%); 21-30% (05%); above 30% (05%)
- Specify safety training for the worker in contracts [questionnaire option (percentage response)]: Yes always (65%); Yes, but only when a client demands (25%); No (05%); Consider unimportant (05%).
- Designate an employee as a project safety coordinator? [questionnaire option (percentage response)]: Yes (70%); No (30%)
- Submit written contractor safety programs with the contract before work begins [questionnaire option (percentage response)]: Yes always (45%); Yes, but only when a client demands (35%); No (20%); Consider unimportant (0%).
- Ways to incorporate safety more effectively on sites through contracts [questionnaire option (percentage response)]: Include proper risk assessment in contracts (30%); Follow international safety standards strictly (10%); the client should be accountable for proper safety insurance in contracts (20%); Worker's training for safety measures should become compulsory (40%).
- Current state of "safety incorporation" in contracts in Pakistan's Construction Sector? [questionnaire option (percentage response)]: Excellent (10%); Good (25%); Average (25%); Poor (40%).

The data analysis suggests that for the majority of respondents, about 20% of the disputes between the contracting parties on their projects are related to construction safety. There is a majority response that suggests that about 10% of the time is spent on resolving contractual safety issues, which account for about 20% of the cost to be incurred. Usually, there is a requirement for workers' safety training. Most respondents believed that workers' safety training should become mandatory in contracts. Towards the end, many respondents perceived the current state of 'contractual safety' provisions to be in a 'poor' state in the local construction industry.

4.3 Analysis of Importance-Usage- Effectiveness of selected contractual provisions and barriers impeding their adoption.

Fig.1a. to Fig. 1b. presents the analysis of the Importance-Usage- Effectiveness of selected contractual provisions. The top and bottom tier of the Likert Scale is presented in Figure 1a and Figure 1b respectively. Fig 2. depicts the perceived significance of barriers.

As per Fig.1a and Fig 1b, contractual provisions related to the safety of site work have been rated as 'very important' followed by 'Availability of Site Engineer' and 'Insurance of work'. There is a general opinion of 'lesser importance' towards the contractual provisions related to environmental safety and labor safety measures on-site. Contractual provisions related to the Safety of site work, care of works, and Insurance of Works have been found to be 'always used'. As seen in Fig.1a and Fig 1b, the environmental safety and labor safety measures on-site are also found to be rarely used. Despite the lower perceived usage and importance of selected contractual provisions, Fig.1a and Fig 1b presents an interesting insight where almost all respondents are found to be of the view that all selected contractual provisions are effective in improving construction safety performance.

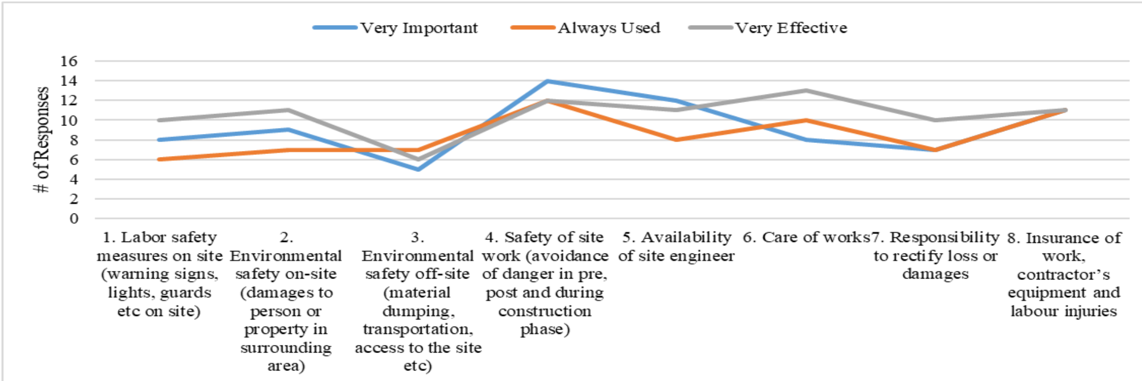

Fig.1a. Top Tier of Importance-Usage-Performance
(Very Important VS Always Used VS Very Effective)

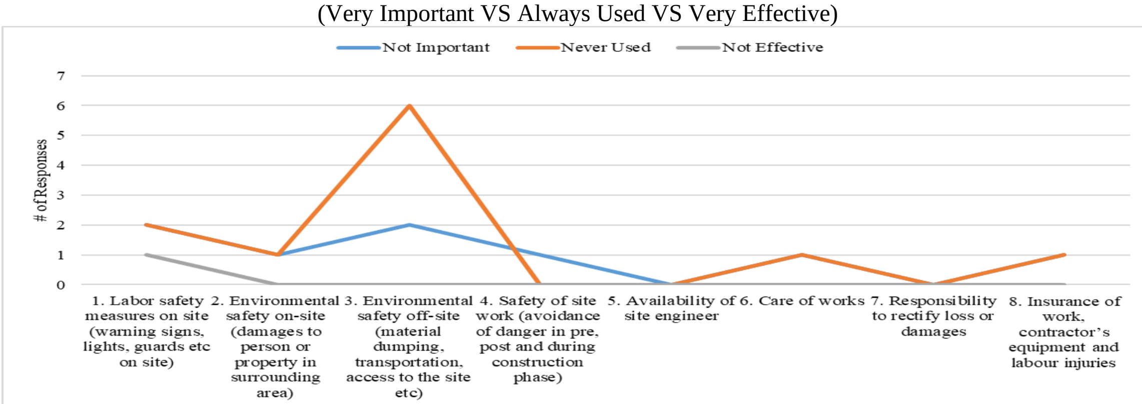

Fig.1b. Bottom Tier of Importance-Usage-Performance
(Not Important VS Never Used VS Not Effective)

Fig. 2 summarizes the responses to the question that asked the respondents to rate the significance of barriers that impede the wide adoption of contractual safety provisions in the local construction industry. A majority of respondents rated cost constraints as extremely significant, followed by poor safety assessment during the bidding stage and resource constraints.

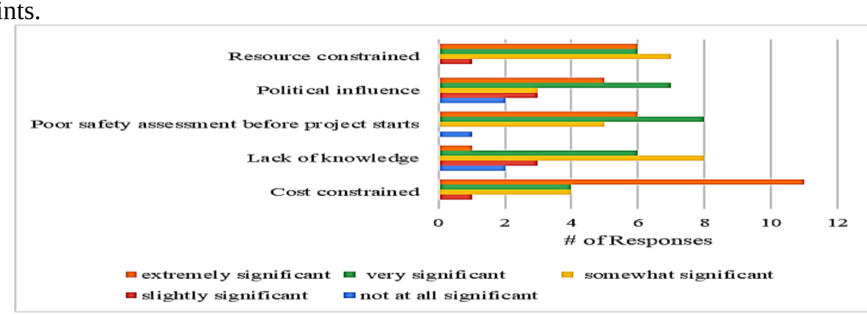

Fig.2. Barriers Impeding Adoption of Contractual Safety

Table 2 presents the descriptive statistics for the responses obtained. There is a relatively low degree of divergence among the respondents for all selected contractual provisions. The mean values of the three parameters for all selected contractual provisions have been found to be in the region of 'excellent to good'.

Table 2. Descriptive Statistics

Contractual Safety Provisions	Importance Mean (SD)	Usage Mean (SD)	Effectiveness Mean (SD)
Labor safety measures on site (warning signs, lights, guards, etc, on site)	2 (1.2)	2.3 (1.3)	2.3 (1.1)
Environmental safety on-site (damages to person or property in surrounding area).	2.05 (1.2)	2.1 (1.1)	2.1 (1.0)
Environmental safety off-site (material dumping, transportation, access to the site etc).	2.4 (1.3)	2.95 (1.7)	2.95 (1.1)

Safety of site work (avoidance of danger in pre, post and during construction phase).	1.7 (1.2)	1.85 (1.2)	1.85 (1.0)
Availability of site engineer.	1.7 (0.98)	1.85 (0.88)	1.85 (1.0)
Care of works.	2.05 (1.2)	1.85 (1.1)	1.85 (1.0)
Responsibility to rectify loss or damages.	2.05 (1.0)	2.15 (1.1)	2.15 (1.1)
Insurance of work, contractor's equipment and labor injuries.	1.9 (1.3)	1.9 (1.3)	1.9 (1.1)

Table 3 presents the ranking of contractual provisions based on the Weighted Average Response from the survey. The ranking criteria looked at the minimum values (in the order) Usage-Importance-Effectiveness. The minimum value was selected because 1 represented the best level for each parameter (Usage-Importance-Effectiveness).

Table 3: Ranking of Selected Contractual Provisions

Ranking of Selected Contractual Provisions	Usage	Importance	Effectiveness
Environmental safety off-site (material dumping, transportation, access to the site, etc.)	4.067	4.800	5.000
Labor safety measures on site (warning signs, lights, guards, etc on site).	4.933	5.333	5.600
Responsibility to rectify loss or damages.	5.133	5.267	5.400
Environmental safety on-site (damages to person or property in the surrounding area).	5.200	5.267	5.533
Insurance of work, contractor's equipment, and labor injuries.	5.467	5.467	5.533
Care of works.	5.533	5.267	5.800
Availability of site engineer.	5.533	5.733	5.667
Safety of site work (avoidance of danger in pre, post and during the construction phase).	5.533	5.733	5.800

4.4 ANOVA Analysis

The results of the One-way ANOVA analysis are presented as follows.

Table 4: One-way ANOVA for Usage~Importance Model

Parameters	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Importance	1	1.2676	1.2676	15.5	0.00765 **
Residuals	6	0.4908	0.0818		

The p-value of the importance parameter is low ($p < \alpha=0.05$), so it appears that the importance of contractual provisions has a statistically significant impact on their usage.

Table 5: One-way ANOVA for Usage~Effectiveness Model

Parameters	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Effectiveness	1	1.4391	1.4391	27.04	0.00201
Residuals	6	0.3193	0.0532		

The p-value of the effectiveness parameter is low ($p < \alpha=0.05$), so it appears that the effectiveness of contractual provisions has a statistically significant impact on their usage.

The results of the Two way ANOVA are as follows.

Table 6: Two-way ANOVA for Usage~Importance+Effectiveness Model

Parameters	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Importance	1	1.2676	1.2676	26.075	0.00375 **
Effectiveness	1	0.2477	0.2477	5.095	0.07360
Residuals	5	0.2431	0.0486		

Adding Effectiveness or Importance to the model seems to have made the model better: it reduced the residual variance (the residual sum of squares went from 0.4908 to 0.2431 or 0.3193 to 0.2431), and Importance is statistically significant (p-values < 0.05); whereas Effectiveness has not been found statistically significant (p-values > 0.05);

The results of the Two-way ANOVA for the Interaction Model are shown in Table 8 below. In Table 8 above, the Importance: Effectiveness variable has a low sum-of-squares value and a high p-value, which means there is not much variation that can be explained by the interaction between Importance and Effectiveness. The last step in the ANOVA analysis is the selection of best model. The performance of all models is summarized in Table 9 below.

Table 7: Two-way ANOVA for Interaction Model

Parameters	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Importance	1	1.2676	1.2676	31.553	0.00494 **
Effectiveness	1	0.2477	0.2477	6.166	0.06798
Importance: Effectiveness	1	0.0824	0.0824	2.051	0.22541
Residuals	4	0.1607	0.0402		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1

An estimate of prediction error and, hence, of the relative quality of statistical models for a certain set of data is the Akaike information criterion (AIC). AIC calculates the relative quality of each model in a set of data models by comparing it to all the other models. AIC therefore offers a model selection method. (Stoica & Selen, 2004; McElreath, 2020; Taddy, 2019).

Table 8: Performance of All Models and Selection of Best Fit Model

Parameters	K	AICc	Delta_AICc	AICcWt	Cum.Wt	LL
Usage~Effectiveness	3	8.93	0.00	0.83	0.83	1.53
Usage~Importance	3	12.37	3.44	0.15	0.98	-0.19
Usage~Importance+Effectiveness	4	16.09	7.15	0.02	1.00	2.62
Interaction	5	31.44	22.51	0.00	1.00	4.28

The model that fits the data the best and is listed first in Table 9 has the lowest AIC value. These findings suggest that the Usage-Effectiveness model provides the best fit. This model explains 83% of the total variation in the dependent variable which can be explained by the entire set of models, as it has the lowest AIC value and 83% of the AIC weight. Although the model with the importance term contains an additional 15% of the AIC weight, it is not a best-fit model because it performs worse than the best model by more than one delta-AIC.

5. Conclusions and Recommendations

Construction has historically been guilty of poor safety performance. The construction engineering and management fraternity has been trying to find ways to improve safety performance for quite a while. Worldwide, construction safety still remains quite dangerous, and in developing nations like Pakistan, improvement to construction safety is much more challenging. The projects are executed where construction safety is usually not a priority; given other aspects trying to capture the available resources. Therefore, it may be the time when contracting parties are held contractually liable for better safety performance to help them prioritize safety as well. With this notion, the study was carried out to benchmark the perception of local industry.

Contractual safety issues and disputes represent a considerable burden for the local construction industry in terms of time, cost, and magnitude. Although the majority of the contractors submit written safety programs, the respondents viewed mandatory worker training as one of the mechanisms for improving safety performance. The respondents perceived the "safety incorporation" in contracts in Pakistan's Construction Sector as 'Poor'. Inferentially, it appears that the importance of contractual provisions has a statistically significant impact on their usage. Furthermore, the effectiveness of contractual provisions has a statistically significant impact on their usage. By adding the parameter of Effectiveness or Importance to the model, it appears to have made the model perform better. The Usage-Effectiveness model is found to be the best fit among the different models, explaining 83% of the total variation in the dependent variable (Usage) by the entire set of models.

The limitations of the current study relate to the data set; it is recommended to undertake the study with more data sets. The data can be collected from different sectors of the construction industry and from different projects. A case study approach can also be undertaken to assess the contractual provisions related to safety between the respective contracting parties. Most respondents mentioned poor safety assessment during the bidding stage and resource constraints as some of the barriers impeding the wide adoption of contractual safety measures. It is therefore recommended that, in light of international best practices, may be employed while the projects are being pursued. Case studies may be planned to be executed and documented with the collaboration of academia and industry so that evidence can be established regarding contractual safety provisions in the local industry. It is also recommended to include relevant details in the curriculum at undergraduate, graduate, continuing education, and professional development courses by concerned higher education institutions, professional development bodies, and other training institutions.

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Contractor's Controlling Factors Contributing to Effective Construction Waste Management in Building Construction

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Abstract

The rapid expansion of global urbanization has resulted in an exponential increase in the number of construction projects, which in turn has led to a surge in construction waste (CW). Effective construction waste management (CWM) has become an urgent need to mitigate the negative impact of CW on the environment, society, and the economy. All key stakeholders involved in the construction industry, including consultants, designers, contractors, subcontractors, suppliers, and government agencies, are responsible for minimizing CW. Among these stakeholders, contractors play a crucial role in managing material usage at construction sites, and improving their capacity for effective CWM is essential to minimizing CW. In this study, 43 articles were reviewed to identify the factors relevant to contractors contributing to effective CWM in building construction. A total of 53 factors were identified, then analyzed, and synthesized into seven categories: i. Management and leadership (14 factors), ii. Manpower (4 factors), iii. Policy and strategy (7 factors), iv. Materials (7 factors), v. Equipment and tool (5 factors), vi. Construction method and process (10 factors), and vii. Documentation (6 factors). These findings contribute to the existing literature on CWM in building construction by identifying the factors that are critical for contractors to consider in achieving effective CWM. In future research, these factors will be further analyzed and utilized as attributes for developing a maturity model for contractors to assess their CWM in building construction. Such a model will help contractors evaluate their CWM performance and identify areas for improvement, ultimately leading to better CWM practices in the construction industry.

Keywords

Construction Waste Management, Contractors, Sustainable Construction, SDGs

1. Introduction

Construction waste (CW) has drastically expanded over the past few decades, making it a global issue. CW makes up around 30% of all solid waste produced worldwide(Bao *et al.*, 2023) in which the annual generation of solid waste is roughly 2.25 billion tons in 2022 (World-Bank, 2022). CW is a significant economic development issue for most countries. The more CW generated could increases the cost of construction projects, as it requires additional cost for materials, transportation, landfill fees, and labor costs. CW takes up valuable land space that could be used for other economic activities, reducing its overall economic value. Improper disposal of CW can lead to environmental degradation, causing soil, water, and air pollution, which can harm the health of local communities, ultimately resulting in increased healthcare costs, and decreased property values. The construction industry is a significant consumer of natural resources, and inefficient management of these resources can result in depletion, leading to increased costs and decreased economic growth (Bao *et al.*, 2023; World-Bank, 2022).

Effective construction waste management (CWM) is essential for economic development as it can reduce costs, preserve land resources, protect the environment, and ensure the sustainability of the construction industry (Bao *et al.*, 2023). CWM is the application of knowledge, skills, tools, and techniques to construction activities to minimize construction waste (Brioso, 2015; Sasitharan Nagapan *et al.*, 2012). Effective CWM can be achieved by addressing all related factors affecting CWM in management and leadership, manpower, policy and strategy, materials, equipment or tools, construction method and process, and documentation. So, reviewing and identifying as well as integrating all factors affecting the effectiveness of CWM are the objectives of this study.

The global construction sector is expanding due to the potential for construction to boost economic growth and quality of life. The expansion of buildings leads to a sharp rise in CW, which calls for immediate and effective

CWM to minimize waste generation. CW is the byproducts from construction activities, such as concrete, mortar, steel, broken bricks, timber, aluminum, glass, tile, plasterboard, paper, plastics, and other materials (Ganiyu et al., 2020). The efficiency of the construction sector and the environment are both directly impacted by CW generation. Construction projects often experience cost overruns of between 21 and 30% due to material waste (Nilupa et al., 2015). Arguable, the contractors have been viewed as the main party generating massive CW (Janani et al., 2022). According to Nilupa et al. (2015), contractors experience a loss of profit as a result of higher overhead costs and delays, a loss of productivity as a result of more time spent cleaning, and high waste disposal costs as a result of waste generation. It is necessary to understand the importance of CWM to motivate stakeholders, especially contractors, to improve their construction waste management, which would help minimize CW to achieve related goals.

A number of research studies were carried out to identify the factors contributing to the influence of effective CWM and make suggestions for improving those factors to minimize CW (Ganiyu et al., 2020). Identifying and integrating those factors would help to facilitate contractors in determining all causing factors that they would need to improve to get themselves to be more productive with their performance of CWM.

Reduce and Reuse are the two alternatives mainly concerned with the contractor's control in building construction (Kabirifar et al., 2020b; Li et al., 2022; Wu et al., 2017). So, the contractor's controlling factors contributing to effective CWM in building construction are primarily identified based on the alternatives mentioned above.

2. Reviews of previous studies

The construction sector has been identified as a significant contributor to the generation of construction waste (CW). To tackle this issue, several studies have been conducted to explore potential methods for minimizing CW production throughout the various stages of construction, including planning, design, procurement, construction, renovation, and demolition, from various perspectives such as environmental, social, economic, and technical. Newaz et al. (2022) have pinpointed multiple elements that impact CWM streams, which comprise the economic value of diverted materials, onsite sorting potential, knowledge, experience, and training of site operatives, accurate predictions of waste management (WM) costs during tenders, and the identification of improved approaches for CW collection and disposal. Lu et al. (2021) have analyzed the framework of a "zero-waste construction site" by specifying its meaning, system boundary, assessment period, and operation strategies. This investigation demonstrates that achieving the objective of zero-waste is challenging but feasible at individual construction sites. In addition, Lu et al. (2010) have examined the crucial success factors for WM in construction projects, revealing critical success factors, including WM regulations, WM system, awareness of CWM, the utilization of low-waste building technologies, minimized design changes, and staffs training in WM.

Other effective CWM factors for building construction have been reviewed and categorized into the following sections.

2.1. Management and leadership

Effective management and leadership are critical factors contributing to the efficiency of CWM (Begum et al., 2009; Cha et al., 2009). In particular, Saheed O. Ajayi et al. (2017) argue that contractors' management with high waste management (WM) commitments is essential to reducing construction waste. Moreover, Bao et al. (2021) suggest that effective site management can minimize the amount of waste generated during construction. Hence, to enhance CWM, contractors should prioritize improving their management and leadership towards CWM. This can be achieved, for example, by implementing an organization breakdown structure for CWM and ensuring its effective implementation (Cha et al., 2009; Tam, 2008), providing adequate supervision of WM activities with clear instructions (Bakshan et al., 2017; Udawatta et al., 2015), and maintaining precise on-site material control, including inspecting all processes, such as materials upon arrival (Janani et al., 2022; Osmani et al., 2008).

2.2. Manpower

Construction projects rely heavily on human resources, making manpower a crucial factor in ensuring CWM. Cha et al. (2009); Newaz et al. (2022) have identified manpower as one of a key factor contributing to the effectiveness of CWM. To minimize CW at project sites, both studies highlight the importance of providing training and education to staff and workers on CWM management. Umar et al. (2016) similarly noted that inadequate on-site WM can lead to low productivity, which can be attributed to the lack of manpower development. De Magalhães et al. (2017) underscored the significant impact of unskilled labor on material waste and rework. These findings emphasize the critical role of manpower development in CWM, which can help reduce waste and increase productivity in construction projects.

2.3. Policy and strategy

Effective CWM is a crucial for contractors to ensure sustainability and reduce environmental impacts. Number of studies have identified several factors that contribute to the effectiveness of CWM. Among these, a clear policy and strategy are considered essential (Ghaffar et al., 2020; Wang et al., 2014). Bakshan et al. (2017) noted that financial incentives are crucial in promoting waste minimization practices and encouraging construction workers to adhere to WM policies and strategies. Furthermore, Newaz et al. (2022) suggested that contractors should have a formal plan for their WM practices, which includes a WM policy as a necessary component. Such a policy should outline the contractor's commitment to CWM, its objectives, and the strategies intends to implement to achieve effective CWM. This plan can help contractors to monitor and evaluate their CWM practices, identify areas for improvement, and measure their success in achieving their goals.

So, a well-defined policy and strategy, financial incentives, and a formal plan are essential for effective CWM practices.

2.4. Materials

A significant contributor to the effective CWM is material waste. Various studies have highlighted the importance of efficient material delivery and management to reduce CW. For instance, Cha *et al.* (2009); Poon *et al.* (2004); Udawatta *et al.* (2015), emphasized the significance of material use as a key factor in effective CWM. Moreover, Saheed O Ajayi et al. (2017) pointed out that the efficient delivery schedule, usage of the Just in Time delivery (JIT) system, and effective delivery of materials, including efficient job site access, and material protection during loading, transportation, and unloading can help minimize CW.

In addition, Ghaffar et al. (2020) suggested that building materials should retain their value with valuable materials and products, which can also contribute to CW reduction. Similarly, Daoud *et al.* (2021) highlighted that the use of good quality, durable, and standardized materials can help reduce CW.

So, it is suggested that minimizing CW in the building construction requires a combination of factors, including efficient material delivery, use of valuable building materials, and utilization of good quality, durable, and standardized materials. These measures can enhance the effectiveness of CWM and contribute to effective CWM practices (Ajayi *et al.*, 2018; Daoud *et al.*, 2021).

2.5. Equipment and tool

The efficiency and effectiveness of CWM is heavily reliant on the application of appropriate equipment and tools. Previous research studies have consistently identified equipment and tools as key factors contributing to the effectiveness of CWM (Cha et al., 2009; Kabirifar et al., 2020b; Kolaventi et al., 2018). Wu et al. (2017) further emphasized that the availability of sufficient equipment with advanced construction technologies is necessary for construction projects to minimize CW generation.

In order to optimize construction processes and reduce waste, adoption of high technologies is recommended. One such technology is Building Information Modeling (BIM), which has been shown to facilitate construction work and help reduce waste (Ajayi et al., 2015; Bao et al., 2020; Ghaffar et al., 2020). The utilization of BIM in construction projects allows for improved collaboration, enhanced visualization, and better project management. Consequently, BIM can help minimize material waste, reduce project timelines, and enhance project outcomes.

The effective CWM is dependent on the application of appropriate equipment and tools. The adoption of other related advanced construction technologies can further facilitate construction work and help reduce waste. So, it is crucial for contractors to prioritize the availability and utilization of appropriate equipment and technologies to optimize construction processes and minimize waste generation (Kabirifar *et al.*, 2020a; Tam, 2008).

2.6. Construction method and process

Ajayi et al. (2018); Cha et al. (2009); Kolaventi et al. (2020) have all recognized construction methods and processes as primary factors in the generation of CW. In order to minimize CW, it is necessary to provide adequate site space and layout for materials movement, as highlighted by (Bao et al., 2020; Wang et al., 2010; Yuan, 2013b). To further minimize CW, it is recommended that separate bins be set up for waste types and that individual waste be sorted by type from mixed waste at the site with notice categories (Ganiyu *et al.*, 2020; Kolaventi *et al.*, 2020; Newaz *et al.*, 2022). Moreover, bins should be installed on every floor to facilitate waste segregation and disposal, as suggested by (Newaz et al., 2022).

The adoption of prefabricated structural elements and preassembled components such as bathroom and kitchen pods can also help to minimize CW (Daoud et al., 2021; Ghaffar et al., 2020). In addition, maximizing the reuse of construction materials at the site is necessary (Ghaffar *et al.*, 2020). To minimize CW from application processes, (Janani et al., 2022; Osmani et al., 2008; Udawatta et al., 2015) strongly recommend the use of effective and efficient construction techniques.

Finally, it is important to implement an effective waste management (WM) plan to ensure the success of effective CWM. As Lu *et al.* (2021) have highlighted, the effective implementation of a WM plan is crucial for the success of CWM. Overall, these strategies can help to minimize CW during the construction process and promote effective CWM.

2.7. Documentation

Effective document control is a crucial factor for ensuring the smooth running of construction projects, as noted by several studies. Ajayi et al. (2018); Kolaventi et al. (2020) both emphasized the importance of document control in achieving an effective CWM. Similarly, Udawatta et al. (2015); Zhao et al. (2022) argued that proper construction documentation is essential for successful CWM. Minimizing variation orders and design changes during construction is also important for reducing CW, according to (Ajayi et al., 2015; Doust et al., 2020). These authors highlighted the need to consider such factors during the construction process to prevent unnecessary CW generation. Furthermore, obtaining professional quality management and certification (such as ISO, GREEN, etc.) has been found to be a means of reducing CW (Andersson *et al.*, 2022; Ghaffar *et al.*, 2020). Such certifications provide contractors with the necessary procedure to implement effective WM strategies and minimize their environmental impact.

Finally, the importance of maintaining a lesson-learned repository or recording of CWM cannot be overstated (Janani et al., 2022; Li et al., 2022). This documentation is essential for future learning and gradual improvement in CWM practices, enabling contractors to continuously improve their CW strategies and minimize waste generation in the long run.

The details extracted contractor's controlling factors contributing to effective CWM in building construction is shown in Table 1.

Table 1. The extracted contractor's controlling factors contribute to effective CWM in building construction.

No.	Factors/ Attributes	References
I.	***Management and leadership***	
1.	Contractor's awareness of CW impacts on sustainable construction (environmental, economic, and social)	(Fernández-Sánchez *et al.*, 2010; Wang *et al.*, 2014; Zulu *et al.*, 2022)
2.	Contractor's effective and efficient site management (planning, execution, monitoring, and control)	(Bao *et al.*, 2021; Osmani *et al.*, 2008)
3.	Contractors' precise on-site material control (including inspection of all processes, e.g., inspect the materials when they arrive, etc.)	(Janani *et al.*, 2022; Osmani *et al.*, 2008)
4.	Senior management behavior and attitude on CWM	(Begum *et al.*, 2009; Wang *et al.*, 2014)
5.	Contractor's adequate supervision of WM activities with clear instructions	(Bakshan *et al.*, 2017; Udawatta *et al.*, 2015)
6.	Effective coordination and communication among project stakeholders (Contractor vs. designer, consultant, client, subcontractor, supplier, etc.)	(Kabirifar *et al.*, 2020b; Osmani *et al.*, 2008)
7.	Contractor's work experience on CWM and waste minimization culture within the company	(Bakshan *et al.*, 2017; Li *et al.*, 2022)
8.	Contractor's action to reduce CW generation	(De Magalhães *et al.*, 2017)
9.	Contractor's action to reuse CW	(Wu *et al.*, 2017)
10.	Contractor detailed study and well understanding of specifications and drawing and on-time accurate quantification of material/ bill of quantity	(Kabirifar *et al.*, 2020a; Poon *et al.*, 2004)
11.	Organization breakdown structure for CWM	(Cha *et al.*, 2009; Tam, 2008)
12.	Prevent site accidents	(Doust *et al.*, 2020)
13.	Monitor and audit waste management system periodically	(Ghaffar *et al.*, 2020; Tam, 2008)
14.	Looking for and having support from the client (the project owner)	(Kolaventi *et al.*, 2018)
II.	***Manpower***	
15.	Training and education of the engineers and workers on WM and its effectiveness	(Ding *et al.*, 2018; Udawatta *et al.*, 2015)
16.	Workers are assigned solely for waste minimization	(Cha *et al.*, 2009; Kolaventi *et al.*, 2020)
17.	Skilled workers and workmanship	(Kabirifar *et al.*, 2020a)
18.	Engagement of all stakeholders in CWM	(Udawatta *et al.*, 2015)
III.	***Policy and strategy***	
19.	Establish a strict policy on CWM within the company (including the CWM system, criteria for the quality and safety of reusable materials, etc.)	(Andersson *et al.*, 2022; De Magalhães *et al.*, 2017; Ghaffar *et al.*, 2020; Kolaventi *et al.*, 2020; Lu *et al.*, 2010)
20.	REDUCE target for every project and maximize material reduction at the construction site	(Daoud *et al.*, 2021; Ghaffar *et al.*, 2020; Menegaki *et al.*, 2018; Yuan *et al.*, 2022)
21.	REUSE target for every project and maximize material reuse at the construction site	(Saheed O. Ajayi *et al.*, 2017; Menegaki *et al.*, 2018; Wang *et al.*, 2014)
22.	Establish an appropriate waste management plan in an earlier stage of each construction (Including methods to deal with reusable materials)	(Cha *et al.*, 2009; Kolaventi *et al.*, 2020) (Newaz *et al.*, 2022; Poon *et al.*, 2004)

No.	Factors/ Attributes	References
23.	Contractual documents may include WM targets and responsibilities of sub-contractors about decreasing waste and increasing reusable waste (i.e., setting criteria)	(Cha *et al.*, 2009; Ghaffar *et al.*, 2020; Osmani *et al.*, 2008; Zhao *et al.*, 2022)
24.	Financial rewards and incentives for the effectiveness of decreasing and reusing waste	(Jaillon *et al.*, 2009; Kabirifar *et al.*, 2020a; Menegaki *et al.*, 2018)
25.	Contractor's current waste assessments score and future target	(Kolaventi *et al.*, 2020; Li *et al.*, 2022)
IV.	***Materials***	
26.	Having central areas for cutting and storage	(Poon *et al.*, 2004; Tam, 2008)
27.	Adequate protection of material transportation and handling (loading and unloading)	(Saheed O Ajayi *et al.*, 2017; Daoud *et al.*, 2021; Osmani *et al.*, 2008)
28.	Adequate protection of different categories of materials during storage and stacking	(Kabirifar *et al.*, 2020b; Poon *et al.*, 2004; Tam, 2008)
29.	Preventing ordering errors and ordering appropriate material sizes and quantities to avoid excess	(Doust *et al.*, 2020; Janani *et al.*, 2022; Osmani *et al.*, 2008)
30.	Use of quality and durable, and standardized materials	(Ajayi *et al.*, 2018; Daoud *et al.*, 2021)
31.	Adopt Just in Time delivery (JIT) system	(Daoud *et al.*, 2021)
32.	Strong security at the project site (i.e., prevent the loss of materials)	(Fernández-Sánchez *et al.*, 2010)
V.	***Equipment/ tool***	
33.	Use and familiar with the application of BIM	(Ajayi *et al.*, 2015; Ganiyu *et al.*, 2020)
34.	Use and familiar with other related information technologies	(Kabirifar *et al.*, 2020a; Tam, 2008)
35.	Availability and quality of Equipment (tools, machines, and vehicles)	(Wang *et al.*, 2010; Wu *et al.*, 2017)
36.	Use and familiar with the Equipment	(Jaillon *et al.*, 2009; Poon *et al.*, 2004)
37.	Use metal scaffolding and formwork (e.g., rent them from professional suppliers)	(Ding *et al.*, 2018; Tam, 2008; Wang *et al.*, 2014)
VI.	***Construction method and process***	
38.	Adequate site space and the site layout are cleared for materials movement	(Bao *et al.*, 2020; Wang *et al.*, 2010; Yuan, 2013b)
39.	Set up separated bins by waste type and sort out individual waste by type from mixed waste at the site with notice categories	(Cha *et al.*, 2009; Kolaventi *et al.*, 2020; Newaz *et al.*, 2022; Wang *et al.*, 2010)
40.	Efficient use of materials and minimizing the uneconomical cutting shapes and length (including rebar schedule and materials lists to be reused)	(Doust *et al.*, 2020; Osmani *et al.*, 2008; Yuan, 2013a)
41.	Effective implementation of a waste management plan	(Lu *et al.*, 2021; Newaz *et al.*, 2022)
42.	Store waste in easily accessible areas	(Yuan, 2013a)
43.	Bins are installed on every floor	(Newaz *et al.*, 2022)
44.	Adopt prefabricated structural elements	(Daoud *et al.*, 2021)
45.	Adopt preassembled components such as bathroom & kitchen pods	(Daoud *et al.*, 2021)
46.	Minimize waste from application processes (i.e., overpreparation of mortar)	(Janani *et al.*, 2022; Osmani *et al.*, 2008; Udawatta *et al.*, 2015)
47.	Minimize rework at the construction site	(Ding *et al.*, 2018; Yuan *et al.*, 2022)
VII.	***Documentation***	
48.	Variation orders minimization	(Daoud *et al.*, 2021)
49.	Document control of CWM with effectiveness (amounts, kinds, etc.)	(Zhao *et al.*, 2022)
50.	Design changes during construction minimization	(Ajayi *et al.*, 2015; Doust *et al.*, 2020)
51.	Shop drawing detailing errors preventing	(Ajayi *et al.*, 2018; Doust *et al.*, 2020)
52.	Professional quality management and certification (e.g., ISO, GREEN, etc.)	(Andersson *et al.*, 2022; Ghaffar *et al.*, 2020)
53.	Lesson learned repository on CWM	(Janani *et al.*, 2022; Li *et al.*, 2022)

3. Methodology

A literature review is a strategy for gathering and synthesizing prior works that are more or less systematic. An in-depth understanding of a particular research subject is facilitated by a literature review, which also lays a strong foundation for the creation of theory and knowledge (Zhao et al., 2022).

A systematic review of prior publications that are pertinent to CWM is conducted in this work. In order to address specific research problems, a systematic literature review method was used to summarize all related study findings that matched the pre-defined inclusion criteria (Zhao et al., 2022). To find relevant papers, the Scopus search engine was mainly used. Scopus was chosen because it performs the search accurately (Darko et al., 2017) and includes more journal articles than other databases like Web of Science (Chadegani et al., 2013). In addition, Scopus is frequently utilized in review journal articles for construction management (Jin et al., 2019). Only journal papers were chosen for this study's analysis. This is because most systematic literature studies solely utilize journal papers, which are known to be the most relevant and reliable research outputs (Zhao et al., 2022).

The terms "factor," "construction," "building," "waste," and "management" were used in the literature search on Scopus. A list of 63 journal articles was generated from the initial search. The screening process involved a rigorous examination of the titles, abstracts, and keywords. Finally, factor extraction was performed using 43 sorted journal articles. The earliest one was published in 1996 by (Bossink et al., 1996), while the most recent one was published in 2023 by (Bao et al., 2023).

All factors used for the “frequency analysis” came from a thorough literature review. The literature review methodology is shown in Figure 1.

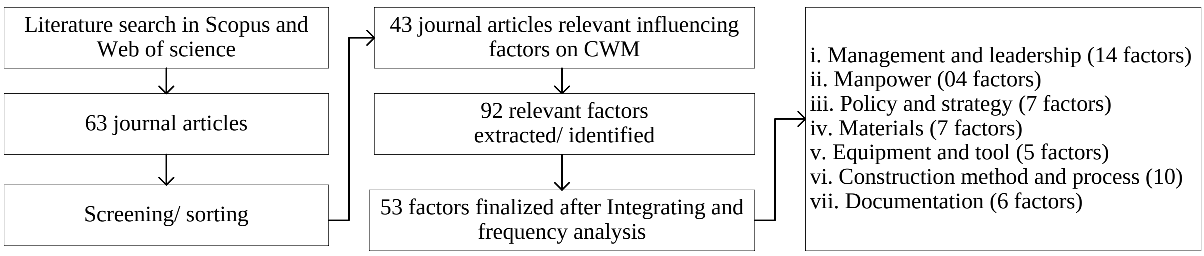

Fig. 1. Literature review methodology

4. Findings and discussions

The aim of this study was to identify the factors that contribute to effective CWM in building construction, with the objective of minimizing the generation of waste through prevention and reuse. The total of 43 articles were reviewed and extracted 92 potential factors that were subsequently analyzed using frequency analysis to identify the most common factors. Factors with a frequency of at least 86% were considered acceptable(Soewin et al., 2022), while factors with a frequency of less than 14% were removed, except for two factors that were retained with a frequency of 13.3%. The remaining 53 factors were classified into seven categories: management and leadership, manpower, policy and strategy, materials, equipment and tool, construction method and process, and documentation. Table 2 bellow presents a comprehensive overview of analysis of the various factors that contribute to effective CWM.

Management and leadership is the most extensively studied category, with the highest number of studies (33) conducted on contractor's awareness of CWM impacts on sustainable construction. The studies highlight the importance of the contractor's effective and efficient site management, precise on-site material control, and senior management's behavior and attitude on CWM. Additionally, contractors' adequate supervision of WM activities with clear instructions, effective coordination and communication among project stakeholders, work experience on CWM, and waste minimization culture within the company are also critical for effective CWM.

In the manpower category, training and education of the engineers and workers on WM and its effectiveness were the most studied factor (33 studies), followed by assigning workers solely for waste minimization (17 studies). Skilled workers and workmanship and engagement of all stakeholders in CWM were also identified as important factors.

Policy and strategy category emphasizes the importance of establishing a strict policy on CWM within the company, setting REDUCE and REUSE targets for every project, and establishing an appropriate WM plan in the early stages of each construction project. The studies also suggest that contractual documents may include WM targets and responsibilities of sub-contractors about decreasing waste and increasing reusable waste, financial rewards and incentives for the effectiveness of decreasing and reusing waste, and contractors' current waste assessment ability and future targets.

In the materials category, having central areas for cutting and storage, adequate protection of material transportation and handling, and adequate protection of different categories of materials during storage and stacking are critical factors in effective CWM. The studies also emphasize preventing ordering errors, ordering appropriate material sizes and quantities to avoid excess, and using quality, durable, and standardized materials.

In the equipment/tool category, it is suggested the importance of using and being familiar with the application of BIM and other related information technologies. Additionally, the availability and quality of equipment, use and familiarity with the equipment, and the use of metal scaffolding and formwork are also important for effective CWM.

In the construction method and process category, it is highlighted the importance of adequate site space and the site layout being cleared for materials movement, setting up separated bins by waste type and sorting out individual waste by type from mixed waste at the site with notice categories, and efficient use of materials and minimizing the uneconomical cutting shapes and length. Effective implementation of a WM plan, storing waste in easily accessible areas, and adopting prefabricated structural elements and preassembled components such as bathroom and kitchen pods are also important.

Lastly, it is suggested that minimizing variation orders, controlling CWM documentation with effectiveness, minimizing design changes during construction, preventing shop drawing detailing errors, and maintaining a lesson learned repository on CWM are critical in the documentation category. Professional quality management and certification, such as ISO and GREEN, are also important.

Therefore, the results showed a comprehensive overview of the various factors that contribute to effective CWM in building construction. It highlighted the importance of management and leadership, manpower, policy and strategy, materials, equipment/tool, construction method and process, and documentation in effective CWM. The findings of this study can be used by contractors to improve their CWM in building construction.

Table 2 is depicted the details results by frequency analysis.

5. Conclusion

The purpose of this study was to identify the factors that contribute to effective CWM in building construction. The total number of 43 articles were reviewed and extracted 92 potential factors, which were subsequently analyzed using frequency analysis. Factors with a frequency of at least 86% were considered acceptable, and those with less than 14% were removed, except for two factors that were retained with a frequency of 13.3%. The remaining 53 factors were classified into seven categories: management and leadership, manpower, policy and strategy, materials, equipment/tool, construction method and process, and documentation.

It is found that effective management and leadership is critical in effective CWM, with the highest number of studies conducted on contractor's awareness of CWM impacts on sustainable construction. Additionally, the study identified training and education of the engineers and workers, assigning workers solely for waste minimization, and engagement of all stakeholders as important factors in the manpower category. The importance of establishing a strict policy on CWM, setting REDUCE and REUSE targets for every project, and establishing an appropriate WM plan in the early stages of each construction project were identified as important factors in the policy and strategy category.

In the materials category, adequate protection of material transportation and handling, and adequate protection of different categories of materials during storage and stacking were critical factors. In the equipment or tool category, it is suggested that the use and familiarity with the application of BIM and other related information technologies, and the availability and quality of equipment are important for effective CWM. The construction method and process category highlighted the importance of adequate site space, separated bins by waste type, and efficient use of materials.

Lastly, in the documentation category, it is suggested that minimizing variation orders, controlling CWM documentation with effectiveness, and maintaining a lesson learned repository on CWM are critical.

These findings can be used by contractors to improve their CWM in building construction.

6. Limitations and future study

The present study focuses on identifying the contractor’s controlling factors that contribute to the effective implementation of CWM in building construction. However, it is important to note that this study does not encompass the influencing factors that are associated with the stages of design, procurement, renovation, and demolition. Subsequent to the findings of this study, further research is being conducted to explore the aforementioned influencing factors in greater detail. The contractor’s controlling factors identified in this study will be used as attributes to develop a maturity model for contractors to assess their implementation of CWM in building construction.

Table 2. The contractor's controlling factors contribute to effective CWM in building construction.

No.	Categories	Factors/ Attributes	1 (Ganiyu et al., 2020)	2 (Poon et al., 2004)	3 (Lu et al., 2010)	4 (Kabirifar et al., 2020)	5 (Tam, 2008)	6 (Ghaffar et al., 2020)	7 (Kabirifar et al., 2020a)	8 (Daoud et al., 2021)	9 (Wu et al., 2017)	10 (Osmani et al., 2008)	11 (Ajayi et al., 2015)	12 (Li et al., 2022)	13 (Janani et al., 2022)	14 (Jaillon et al., 2009)	15 (de Magalhães et al., 2017)	16 (Bossink et al., 1996)	17 (Ajayi et al., 2018)	18 (Fernández S. et al., 2010)	19 (Andersson et al., 2022)	20 (Ding et al., 2018)	21 (Udawatta et al., 2015)	22 (H. Yuan, 2013)	23 (Saheed O Ajayi et al., 2017	24 (Lu et al., 2021)	25 (Cha et al., 2009)	26 (Kolaventi et al., 2018)	27 (Newaz et al., 2022)	28 (Bao et al., 2020b)	29 (Wang et al., 2010)	30 (Yeheyis et al., 2012)	31 (Bakshan et al., 2017)	32 (Wang et al., 2014)	33 (Begum et al., 2009)	34 (Bao et al., 2021)	35 (Zhao et al., 2022)	36 (Doust et al., 2020)	37 (Menegaki et al., 2018)	38 Kolaventi et al. (2020)	39 (Umar et al., 2016)	40 (Yuan et al., 2022)	41 (Yuan, 2013)	42 (Ajayi et al., 2017)	43 (Zulu et al., 2022)	Number of studies	Number of studies in (%)
1	Management and leadership	Contractor's awareness of CW impacts on sustainable construction (environmental, economic, and social)	√	√	√	√	√	√	√	√	√		√	√			√		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√		√	√					√	**33**	**73.3**
2		Contractor's effective and efficient site management (planning, execution, monitoring, and control)	√		√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√		√			√		√	√	√	√		√	√		√			√			√	√			**29**	**64.4**
3		Contractors' precise on-site material control (including inspection of all processes, e.g., inspect the materials when they arrive, etc.)	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√		√	√			√		√	√	√	√	√	√		√			√					√			**29**	**64.4**
4		Senior management behavior and attitude on CWM	√	√	√	√	√		√	√	√		√	√	√	√	√		√	√	√	√	√						√	√	√		√	√	√	√	√		√							**27**	**60.0**
5		Contractor's adequate supervision of WM activities with clear instructions	√		√	√	√				√	√	√	√	√	√	√	√	√	√		√	√			√			√	√	√		√	√		√			√				√			**25**	**55.6**
6		Effective coordination and communication among project stakeholders (Contractor vs. designer, consultant, client, subcontractor, supplier, etc.)	√	√	√	√		√	√	√	√	√	√			√	√		√		√		√			√	√			√	√		√		√				√				√			**23**	**51.1**
7		Contractor's work experience on CWM and waste minimization culture within the company	√	√		√				√	√	√	√	√	√	√	√	√		√		√	√	√						√			√	√	√											**20**	**44.4**
8		Contractor's action to reduce CW generation		√		√	√		√	√	√		√	√	√	√	√			√	√	√	√										√	√	√		√									**19**	**42.2**
9		Contractor's action to reuse CW		√		√	√		√	√	√		√	√	√	√	√			√	√	√	√										√	√	√		√									**19**	**42.2**
10		Contractor detailed study and well understanding of specifications and drawing and on-time accurate quantification of material/ bill of quantity	√	√	√	√			√	√		√	√		√		√	√	√							√			√	√							√	√								**17**	**37.8**
11		Organization breakdown structure for CWM	√				√		√			√		√	√				√	√	√						√	√	√	√																**13**	**28.9**
12		Prevent site accidents	√		√		√	√				√						√		√			√	√														√								**10**	**22.2**
13		Monitor and audit waste management system periodically					√	√	√		√	√								√	√					√										√										**10**	**22.2**
14		Looking for and having support from the client (the project owner)	√								√					√			√								√	√									√									**7**	**15.6**
15	Manpower	Training and education of the engineers and workers on WM and its effectiveness	√	√	√	√	√	√	√	√	√	√	√	√	√			√		√	√	√	√	√			√	√	√	√			√	√	√		√		√	√	√	√	√		√	**33**	**73.3**
16		Workers are assigned solely for waste minimization							√		√		√	√	√	√						√		√		√	√	√			√		√		√		√			√	√					**17**	**37.8**
17		Skilled workers and workmanship		√				√	√		√			√	√	√	√	√			√	√		√		√							√					√			√					**16**	**35.6**
18		Engagement of all stakeholders in CWM	√	√	√		√	√	√	√			√	√							√	√	√								√		√		√		√									**16**	**35.6**
19	Policy and strategy	Establish a strict policy on CWM within the company (including the CWM system, criteria for the quality and safety of reusable materials, etc.)	√		√	√	√	√		√	√	√	√	√	√	√	√		√		√	√	√		√	√	√	√	√			√	√	√		√	√		√	√	√	√	√	√	√	**34**	**75.6**
20		REDUCE target for every project and maximize material reduction at the construction site	√	√	√	√	√	√		√	√	√	√	√	√	√	√		√			√		√	√	√	√	√				√		√	√		√		√			√		√	√	**29**	**64.4**
21		REUSE target for every project and maximize material reuse at the construction site	√	√	√	√	√	√		√	√	√	√	√	√	√	√		√			√		√	√	√		√				√		√	√		√		√					√	√	**27**	**60.0**
22		Establish an appropriate waste management plan in an earlier stage of each construction (Including methods to deal with reusable materials)		√	√	√		√	√		√	√	√	√	√		√	√	√			√				√	√		√			√	√			√		√	√	√	√	√			√	**26**	**57.8**
23		Contractual documents may include WM targets and responsibilities of sub-contractors about decreasing waste and increasing reusable waste (i.e., setting criteria)	√		√	√	√	√		√	√	√	√		√			√	√				√		√	√	√	√	√			√		√		√	√			√				√		**24**	**53.3**
24		Financial rewards and incentives for the effectiveness of decreasing and reusing waste			√	√			√		√	√	√	√	√	√					√	√	√				√			√			√						√			√	√		√	**19**	**42.2**
25		Contractor's current waste assessments score and future target					√	√	√		√	√	√							√	√					√										√				√		√				**12**	**26.7**

Table 2. The contractor's controlling factors contribute to effective CWM in building construction (continued)

No.	Categories	Factors/ Attributes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	Number of studies	Number of studies in (%)
			(Ganiyu et al., 2020)	(Poon et al., 2004)	(Lu et al., 2010)	(Kabirifar et al., 2020)	(Tam, 2008)	(Ghaffar et al., 2020)	(Kabirifar et al., 2020a)	(Daoud et al., 2021)	(Wu et al., 2017)	(Osmani et al., 2008)	(Ajayi et al., 2015)	(Li et al., 2022)	(Janani et al., 2022)	(Jaillon et al., 2009)	(de Magalhães et al., 2017)	(Bossink et al., 1996)	(Ajayi et al., 2018)	(Fernández S. et al., 2010)	(Andersson et al., 2022)	(Ding et al., 2018)	(Udawatta et al., 2015)	(H. Yuan, 2013)	(Saheed O Ajayi et al., 2017	(Lu et al., 2021)	(Cha et al., 2009)	(Kolaventi et al., 2018)	(Newaz et al., 2022)	(Bao et al., 2020b)	(Wang et al., 2010)	(Yeheyis et al., 2012)	(Bakshan et al., 2017)	(Wang et al., 2014)	(Begum et al., 2009)	(Bao et al., 2021)	(Zhao et al., 2022)	(Doust et al., 2020)	(Menegaki et al., 2018)	Kolaventi et al. (2020)	(Umar et al., 2016)	(Yuan et al., 2022)	(Yuan, 2013)	(Ajayi et al., 2017)	(Zulu et al., 2022)		
27	Materials	Adequate protection of material transportation and handling (loading and unloading)	√	√	√	√	√	√	√	√		√	√		√	√		√						√	√		√	√			√	√				√		√					√			**22**	**48.9**
28		Adequate protection of different categories of materials during storage and stacking	√	√	√	√	√		√	√		√	√		√		√	√							√			√			√	√						√		√						**18**	**40.0**
29		Preventing ordering errors and ordering appropriate material sizes and quantities to avoid excess	√	√	√	√	√	√	√	√		√			√			√					√		√		√									√		√						√		**17**	**37.8**
30		Use of quality and durable, and standardized materials		√	√	√		√		√			√			√		√		√			√		√	√						√							√							**14**	**31.1**
31		Adopt Just in Time delivery (JIT) system	√	√					√	√	√			√				√							√				√	√	√	√				√										**13**	**28.9**
32		Strong security at the project site (i.e., prevent the loss of materials)		√	√	√	√			√		√				√		√		√					√		√					√						√								**14**	**31.1**
33	Equipment/ tool	Use and familiar with the application of BIM	√	√	√	√	√	√	√	√	√		√	√		√			√		√		√	√	√					√		√				√					√				√	**22**	**48.9**
34		Use and familiar with other related information technologies	√	√	√	√	√	√	√	√	√		√	√		√			√		√		√	√	√					√						√					√				√	**21**	**46.7**
35		Availability and quality of equipment (tools, machines, and vehicles)		√	√	√					√			√				√			√			√						√	√										√					**11**	**24.4**
36		Use and familiar with the equipment		√		√		√	√	√	√			√		√					√			√																	√					**11**	**24.4**
37		Use metal scaffolding and formwork (e.g., rent them from professional suppliers)			√	√	√				√			√							√	√		√										√								√				**10**	**22.2**
38	Construction method and process	Adequate site space and the site layout are cleared for materials movement	√	√	√	√	√	√	√	√	√	√	√		√	√	√	√	√	√				√	√		√	√	√	√	√	√			√	√		√		√			√	√		**31**	**68.9**
39		Set up separated bins by waste type and sort out individual waste by type from mixed waste at the site with notice categories	√	√	√	√	√	√	√	√	√			√	√					√	√	√		√		√	√	√	√		√	√				√			√	√	√		√	√		**27**	**60.0**
40		Efficient use of materials and minimizing the uneconomical cutting shapes and length (including rebar schedule and materials lists to be reused)	√		√	√	√	√		√			√			√	√	√	√	√			√	√	√	√		√	√		√	√	√		√			√				√	√			**25**	**55.6**
41		Effective implementation of a waste management plan		√			√	√	√		√	√		√	√		√	√		√	√	√						√	√		√	√	√				√	√	√		√	√				**23**	**51.1**
42		Store waste in easily accessible areas	√	√	√	√	√	√		√		√				√	√			√					√	√	√	√	√	√	√				√	√		√		√				√		**23**	**51.1**
43		Bins are installed on every floor	√		√	√	√	√	√	√	√			√	√					√	√	√		√	√			√	√		√	√							√	√	√					**22**	**48.9**
44		Adopt prefabricated structural elements	√	√	√		√	√	√	√		√		√		√			√			√	√	√	√		√							√			√			√	√	√				**21**	**46.7**
45		Adopt preassembled components such as bathroom & kitchen pods	√	√	√		√	√	√	√		√		√		√			√			√	√	√	√		√							√			√			√	√	√				**21**	**46.7**
46		Minimize waste from application processes (i.e., overpreparation of mortar)	√	√	√		√	√									√	√	√	√	√			√		√		√	√													√				**15**	**33.3**
47		Minimize rework at the construction site	√					√	√						√		√					√			√		√			√					√		√					√				**12**	**26.7**
48	Documentation	Variation orders minimization	√	√					√	√		√	√				√	√	√			√		√	√									√				√						√		**15**	**33.3**
49		Document control of CWM with effectiveness (amounts, kinds, etc.)	√		√	√						√			√	√			√	√			√			√	√	√	√										√	√						**15**	**33.3**
50		Design changes during construction minimization	√	√								√	√				√	√	√					√										√				√						√		**11**	**24.4**
51		Shop drawing detailing errors preventing	√	√								√					√	√	√																			√								**7**	**15.6**
52		Professional quality management and certification (e.g., ISO, GREEN, etc.)						√									√			√	√																		√						√	**6**	**13.3**
53		Lesson learned repository on CWM	√												√			√		√										√				√												**6**	**13.3**
54		**TOTAL**	**37**	**35**	**34**	**34**	**34**	**33**	**33**	**32**	**32**	**31**	**29**	**29**	**29**	**28**	**27**	**26**	**25**	**25**	**24**	**24**	**23**	**23**	**22**	**22**	**21**	**21**	**20**	**20**	**19**	**19**	**18**	**18**	**17**	**17**	**17**	**17**	**17**	**15**	**14**	**14**	**12**	**11**	**10**		

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The Impact of Project Performance on the Image of the Construction Industry in Botswana

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Abstract

The construction industry is one of the largest sectors in the economy of Botswana and contributes average 6.7% of the country's gross domestic product (GDP). Botswana operates a free enterprise economic system. However, Botswana's construction industry is developing and facing the challenge of poor project implementation, resulting in negative perceptions with respect to the sector.

This study focuses on the impact of project performance on the image of the construction industry in Botswana. The quantitative method was adopted for the study and entailed the completion of a self-administered questionnaire by nine industry stakeholder groups. The questionnaire, which was pre-tested on ten industry participants included three sections, namely demographic data, and issues relative to image and industry best practice.

The salient findings include: a range of systems are important in terms of project implementation setup; environmental pollution control instruments are mostly ineffective; the construction industry is generally rated below average relative to seven aspects of project performance in the view of the public and clients, and 92.3% of 26 aspects of project performance are more than important to very important to clients.

Conclusions include: regulatory systems are inadequate; there is no instrument to assess the industry in terms of continuous performance; the negative image of the construction industry is attributed to irresponsible industry role players' behaviour; there is limited skills' capacity, and political interference accompanies project implementation.

Recommendations include: the development and implementation of an industry performance regulatory system to address, *inter alia*, the environment, and health and safety (H&S); the development of construction industry indicators; the review of labour-related legislation within the context of health and safety (H&S); development of capacity in the construction industry, and support of research and development in the construction industry by the industry.

Keywords: Construction, Image, Industry, Performance.

1. Introduction

This paper focuses on the impact of project performance on the image of the construction industry in Botswana based on the findings of a survey conducted on recent projects. Public opinion is essential a business or sector's image, therefore, the investigation endeavoured to establish the sources of negative perceptions towards the construction industry in Botswana, employing established and tested quantitative and qualitative systems. The relationship between, image, project performance and the construction industry form an integral part of the research, and the study brings attention to and creates awareness of the need to improve the image of the construction industry in Botswana. Deficient performance by contractors has delayed the completion of several government-funded projects in Botswana owing to poor construction management, which in turn resulted in cost overruns (Maruapula, 2008).

Contractors faces numerous challenges, *inter alia*, human resource development, capacity development, and lack of competitiveness among citizen firms, therefore the sectors produce non-conforming work (Palalani, 2000). However, Axson (2007) posits that best practices occur relative to industry wide quality assurance systems and appropriately managed resources.

Previous research highlights that the Botswana construction industry is facing challenges in terms of addressing the negative image as perceived by the public. Adeyemi and Masalila (2016) observe minimal improvement in the delivery of projects over the years but a more competitive environment due to an increased number of players. Smallwood (2000) in turn posits that the non-traditional project performance measures are critical in terms of the image of the sector. This research placed more emphasis on the non-traditional measures, which have generally been ignored in the industry. To this end the study sought to determine the: importance of established systems in project implementation setup;;

- effectiveness of environmental pollution control instruments; Identify the causes of the negative public perceptions, the extent of, and impact thereof on the reputation of the construction industry in Botswana;
- rating of project performance in the view of the public and clients, and
- importance of 26 aspects of project performance to clients.

2. Review of the literature

2.1 Macro Environment

The economy of the country is shaped by the macroeconomic environment, and the sector's share in the country's GDP indicates its importance in the economy of that country in comparison to other sectors. In Botswana, the construction sector contributes significantly to the socio-economic development of the country, and therefore its performance cannot be ignored. Fernandes (2014) observes the regional construction sectors' contribution to GDP per country - Zambia (23.1%) predominates, followed by Tanzania (8.8%), Angola (7.8%), Botswana (7.4%), Lesotho (7.5%), and South Africa (4%).

The construction industry, as other sectors, remains susceptible to prevailing political, economic, and other catastrophic national events. During the advent of the COVID-19 pandemic in 2019, the Botswana construction sector recorded a decline of 4.8% in 2021. However, the Botswana government continues to invest in infrastructure development as evidenced by the 2023/2024 budget allocation of P12.73 billion infrastructure development projects (Ministry of Finance, Government of Botswana, 2023).

2.2 Sector comparable factors,

An industry income status provides insight regarding the level of attraction that the industry has in terms of local and international professionals, who in turn can improve the sector. High levels of attrition in a sector are accompanied by a loss of skills capacity.

The construction sector is rated the sixth lowest paying of the thirteen sectors of the economy in Botswana with mining rated first. The average construction sector monthly remuneration is 28% of the monthly remuneration of most paying sectors and therefore, the industry is least attractive to potential new entrants and career aspirants (Statistics Botswana, 2017). Inadequate procurement systems in the construction sector create adversarial relationships among the parties involved, increasing the number of claims and disputes (Ministry of Finance and Development Planning (MFDP), Government of Botswana, 2005). Furthermore, project schedule overruns of 19 months relative to target completion dates are attributed to the procurement model. The cidb (2004) status report affirms that clients and their procurement practices are the drivers of industry behaviour, performance, and transformation.

2.3 What constitutes image?

Theaker (2001) defines image as a perception that exists only in the mind of the receiver to formulate an image; the public interpret an identity in a wider context with broader frames of reference. However, Stapelberg (2002) in Debeer *et al*. (2002) suggests that when public opinion is formed, a certain image of the business is formed. Furthermore, image is affected by performance relative to both the traditional and non-traditional project performance parameters (Smallwood, 2000).

The increase in the number of project failures within the construction industry in Botswana has resulted in discontentment and dissatisfaction, not only in terms of the political leadership, but also among stakeholders. These have affected the image of the construction sector. Mselle and Manis (2000) state that the image of construction firms in Botswana is diminishing because of bad or poor project implementation. It is unfortunate that many organisations in Botswana do not sufficiently emphasise the importance of health and safety (H&S) practices. Briscoe (2004) in turn notes the increased number of accidents at work over the years in Botswana, and states that the lack of a construction sector specific H&S Act contributes to the current negative state of H&S in construction. Lattimore *et al.* (2002) accentuate that once lost, credibility is difficult to regain, individually, or collectively.

2.4 Project performance measures

Previous research conducted by Smallwood (2000) discusses the traditional and non-traditional project performance measures. The traditional performance measures include cost, quality, time, and utility, while the non-traditional project performance measures include the environment, health and safety (H&S), productivity, and worker satisfaction. However, Yip (2000), citing Bishop (1981), affirms the assertion regarding the traditional project measures, namely that "…many clients believe that construction projects are said to cost too much, take too long to complete, and are too prone to failure through non-achievement of quality and utility."

The competent project resource is integral to the success of project performance therefore Botswana government implemented several initiatives to develop the construction sector, However, the mid-term review of the Botswana National Development Plan (Ministry of Finance and Development Planning, Government of Botswana, 2013) highlights the critical shortage of skilled labour despite the country's investment in skills development. Despite this setback, the Botswana government continued to attract entry of multinational firms with the objective to build the capacity of local firms. A similar skills development approach was observed in the United Kingdom as part of the 'Construction Best Practice programme (CBP)' (Sun and Howard, 2006). Poor project performance is attributed to deficient planning, and a shortage of skilled personnel and the resultant outcome is project cost overruns, frequent scope changes, and late completion of projects.

2.5 Projects and the environment

Construction industry activities adversely impact on the environment, either directly or indirectly (Chen & Li, 2006).

Consequently, project performance can be measured against the negative impact it brings to the environment. The firm that is engaged will break or build a relationship with the community it interacts with. Therefore, the image of the organisation is directly associated with the projects they undertake because of the impact thereof on the environment and neighbourhood.

2.5 Contractor health and safety

No workplace can consider itself immune to potential traumatic events and the construction firm's H&S policy needs to encapsulate a policy on how to deal with work-related traumatic incidents. Rowlinson (2004) postulates that the "…construction industry has a distressingly poor safety record, in absolute terms or alongside other industries."

The fact that the construction industry is gender biased towards males, and the environment is nomadic, this is the group mostly exposed to illness. Haupt *et al.* (2005) points out that many men in construction are obliged to leave home and travel long distances to find work and once they have found work, frequently seek out young women and teenage girls for sex and intimacy. It is this perception that portrays the construction industry image negatively whereupon families would not want their spouses associated with such morally compromised conduct.

2.6 Sector productivity

Productivity is defined as the effective and efficient utilisation of resources for increased production value and quality of goods and services (Botswana National Productivity Centre, 2007). Vision 2016 (Government of Botswana, 1997) refers to lower labour productivity in many sectors. While institutional reforms are seen as an absolute solution, the problems remain evident and Bennett (2003) concurs that labour productivity in the construction industry is a major concern among all segments, especially owners and contractors.

2.7 Shortage of skilled project personnel`

Toor and Ofori (2008) recognise that the construction industry faces several technical, social, financial, political, and cultural challenges. Therefore, there is a need to equip the professionals with hard (technical) as well as soft (management and leadership) skills. The Botswana government through the Nation Vision 2016 invested in skills development, however these strategic gains continue to be reversed by the emergence of the national HIV and AIDS pandemic (Ministry of Finance and Development Planning, 2006). The sector work environment influences its capability as observed by Castaneda *et al.* (2005) that decreased real wages, the transient nature of construction, the poor industry image, lack of training, and lack of worker-oriented career path as factors that contribute to the industry's skill gap. Statistics Botswana (2016) states that the construction sector in Botswana continues to show a decline in the number of work permit holders as evidenced by a 66% decline from 2009 to 2014. However, the advent of the COVID-19 pandemic posed serious threat to gains the country had attained.

2.8 Contractor industrial relations

De Beer (2002) posits that staff are responsible for protecting the good name of the business, which is supported by Labuschagne (2002) that employees' welfare is critical to ensure that they in turn have an interest in the welfare of the business. Wellington (2010) affirms that there is a need to invest in the people that deliver the project.

Public perceptions still fault the construction industry as a breeding ground of most illnesses compared to other sectors. This is observed by Haupt *et al*. (2005) that due to mobility and the migrant nature of the construction industry, it is the third hardest hit by the HIV and AIDS pandemic in South Africa. The way construction site activities evolve with people of different cultural backgrounds results in conflict and violence till such time that work groups learn to understand each other in a work environment (Briscoe, 2004).

2.9 The behaviour of contractors

Contractors have contributed in some way to the failure of projects. Ganaway (2006) affirms that construction is inherently a risky business. Hopkins (2015) in turn asserts that projects should be delivered within the traditional project performance measures of cost, quality, and time parameters. Fifkins (2004) also posits that image is based on people's knowledge and experience, which may be good, bad, or indifferent, therefore favourable image must be earned.

The ethical conduct of an individual, group or society results in several benefits, some intangible and ultimately can benefit business in terms of profitability and enhanced organisational reputation with embedded trust thus giving growth opportunities. Unethical conduct exposes the firm to risk of being blacklisted either officially or informally. It becomes difficult for a firm to regain its reputation or trustworthiness once it has crossed the ethical line (Werner, 2007). Negative contractor behaviour in Botswana is noted by Ssegawa *et al.* (2005), that contractors in higher grading categories embezzle project funds resulting in delayed project delivery or abandoned projects.

2.10 Corruption

According to Omotoye (2020), corruption in Botswana's construction industry is not a new phenomenon. It is evident from previous research conducted by Phiri (2010), that corruption through bribery influences project awarding. The construction industry in Botswana is therefore susceptible to corruption as observed by Maruapula (2008) that "...corruption is rampant in project implementation in Botswana." Serite (2018) states that "…Botswana Housing Corporation (BHC) officials are colluding with Chinese construction contractors in the award of lucrative tenders, while local companies are side-lined in almost 90 percent of projects." Kologwe (2013) concurs that BHC favours Chinese firms, while the BHC accuses locals of selling tenders to Chinese companies. It is this background that the cost and impact of corruption on the global construction industry can be viewed from a buyer or seller perspective.

3. Research

3.1 Research Method and Sample Stratum

The quantitative method was adopted for the primary study because it enabled the research to reveal the multi-faceted project implementation process, in that it examines a situation as it is, and it does not involve changing or modifying the situation under investigation, as it focuses on observed behaviour. The research was initiated by observation of the salient aspects that negatively shape or describe a construction site and the neighbourhood environment. Thereafter, a self-administered questionnaire was circulated to obtain empirical data relative to completed projects within the last ten years and on-going projects selected randomly. The questionnaire was categorised in three (3) sections, Section 1 Biographical, Section 2-Demographic data, and Section 3-Industry best practice perceptions.

The sample strata involved an array of construction industry stakeholders ranging from financial institutions, government agencies, private practitioners, developers, project managers and academic institutions.

120 questionnaires were circulated and 101 were completed and returned, which equates to a response rate of 84.2%, which is deemed an acceptable response rate.

3.2 Results

Table 1 indicates the importance of established systems in project implementation setup in terms of percentage responses to a scale of 1 (not important) to 5 (very important), and mean scores (MSs) ranging from 1.00 and 5.00.

It is notable that 5 / 7 (71.4%) MSs are > 3.00, which indicates that in general the respondents view the established systems as more than important as opposed to less than important as in the case of MSs ≤ 3.00. The existence of structured systems would influence performance and subsequently, impact on the image of the sector.

Communication plan ranked first has a MS > 4.20 ≤ 5.00, which indicates that it is between more than important to very important / very important. A clear communication plan is critical to realise project success.

Construction site management, public relations function, and site managers' roles on construction sites have MSs > 3.40 ≤ 4.20, which indicates that they are between important to more than important / more than important. Configuration of company policies to work sites has a MS > 2.60 ≤ 3.40, which indicates that it is between less than important to important / important and is ranked fifth. Need to outsource the public relations function, and alignment of project management training to public relations have MSs > 1.80 ≤ 2.60, which indicates that they are between not important to less than important / less than important.

Table 1. Importance of established systems in project implementation setup.

Established system	Response (%)						MS	Rank
	Un-sure	Not...Very						
		1	2	3	4	5		
Communication plan	2.0	2.0	2.0	4.1	18.4	71.4	4.48	1
Construction site management	2.0	4.1	6.1	8.2	28.6	51.0	4.10	2
Public relations function	4.1	4.1	2.0	18.3	22.4	51.0	4.08	3
Site managers' roles on construction sites	6.1	4.1	4.1	14.3	51.0	20.4	3.61	4
Configuration of company policies to work sites	4.1	6.1	8.2	14.3	20.4	30.6	3.04	5
Need to outsource the public relations function	14.3	14.3	22.4	24.5	14.3	10.2	2.40	6
Alignment of project management training to public relations	10.4	1.2	16.3	28.6	18.4	4.1	2.24	7

Table 2 indicates the effectiveness of six environmental pollution control instruments in terms of percentage responses to a scale of never to always, and MSs ranging between 1.00 to 5.00. It is notable that, 4 / 6 (66.7%) of the MSs are below the midpoint of 3.00, which indicates that in general respondents perceive the existing controls to be not effectively implemented at their organisations.

Contractors' do not implement EMPs, and construction activities pollute the environment regularly to often / often as their MSs are > 3.40 ≤ 4.20.

Enforcement and compliance to statutory requirements, and the impact of construction work on the environment occur seldom to regularly / regularly as their MSs are > 2.60 ≤ 3.40.

Effectiveness of consultation tools, and contractors' attitude towards waste disposal at sites, occur between never to seldom / seldom, as their MSs are > 1.80 ≤ 2.60.

Table 2: Effectiveness of environmental pollution control instruments.

Aspect	Response (%)						MS	Rank
	Unsure	Never	Seldom	Regularly	Often	Always		
Contractors do not implement EMPs	8.1	0.0	6.1	14.3	44.9	26.5	3.67	1
Construction activities pollute the environment	2.0	4.1	12.2	36.7	22.4	24.5	3.51	2
Enforcement and compliance to statutory requirements	6.1	8.1	14.3	36.7	22.4	10.2	2.87	3
The impact of construction work on the environment	6.1	12.2	22.4	28.6	20.4	10.2	2.75	4
Effectiveness of consultation tools	28.6	6.1	18.4	24.5	8.2	14.3	2.20	5
Contractors' attitude towards waste disposal at sites	0.0	6.1	12.2	42.9	20.4	18.4	2.16	6

Table 3 presents the rating of project performance relative to seven aspects in the view of the public and clients according to respondents in terms of percentage responses to a scale of very poor to very good, and MSs ranging between 1.00 to 5.00. It is notable that only 3 / 7 (42.9%) of the MSs are > 3.00, which indicates the rating is above average, as opposed to below average as in the case of MSs ≤ 3.00.

Given that the MS of poor financial planning and management is > 3.40 ≤ 4.20, the rating is between average to good / good.

The MSs of 5 / 7 (71.4%) aspects are > 2.60 ≤ 3.40, which indicates the rating is between poor to average / average - political leadership attitude towards project, contractors' behaviour relative to project resources, effectiveness of procurement systems, construction disputes' publicity, and productivity levels in the construction sector. Except construction disputes' publicity, these aspects all affect efficiency and contractors' performance on projects, and thus their image. The MS of contractors' performance on projects is > 1.80 ≤ 2.60, which indicates the rating is between very poor to poor / poor.

Table 3: Rating of project performance in the view of the public and clients.

Aspect	Response (%)							
	Unsure	Very poor	Poor	Average	Good	Very good	MS	Rank
Poor financial planning and management	2.0	4.1	4.1	20.4	22.4	46.9	3.97	1
Political leadership attitude towards projects	6.1	8.2	16.3	20.4	26.5	22.4	3.20	2
Contractors' behaviour relative to project resources	6.1	2.0	16.3	40.8	24.5	10.2	3.06	3
Effectiveness of procurement systems	4.1	8.2	16.3	44.9	18.4	8.2	2.97	4
Construction disputes' publicity	10.2	6.1	22.4	30.6	20.4	10.2	2.89	5
Productivity levels in the construction sector	12.2	14.3	14.3	24.5	24.5	10.2	2.65	6
Contractors' performance on projects	2.0	34.7	22.4	26.5	8.2	6.1	2.22	7

Table 4 indicates the respondents' perceived importance of 26 aspects of project performance to clients in terms of percentage responses to a scale of not important to very important, and MSs ranging between 1.00 to 5.00. It is notable that 24 / 26 (92.3 %) of the MSs are > 3.00, which indicates that in general the aspects are perceived to be more than important as opposed, to less than important, as in the case of MSs ≤ 3.00.

The top six ranked project performance aspects are quality, time performance, workers' skills, communication, and project administration performance, and health (occupational), which all have MSs > 4.20 ≤ 5.00 (more than important to very important / very important). Quality, which is ranked first, predominates, and is a major performance consideration in project implementation. The latter is followed by time and workers' skills ranked joint second. However, these aspects are related to the top three, and are followed closely by communication, project administration performance, and health (occupational).

The aspects ranked seventh to twenty-third have MSs > 3.40 ≤ 4.20, which indicate they are between important to more than important / more than important. Plant and equipment condition with a MS of 4.20 is ranked seventh, followed by site enclosure with a MS of 4.18 ranked eighth. Thereafter, cost saving / remaining within budget is ranked ninth with a MS of 4.06, marginally ahead of material wastage on site ranked tenth, procurement systems ranked joint eleventh with worker attire (MSs = 3.97), followed by facilities (change rooms, toilets, etc.), and site offices, which are ranked join thirteenth, followed by own environment consciousness (MS = 3.93). These in turn are followed by industrial relations, relations with site neighbours, and storage ranked joint sixteenth (MSs = 3.87). Project signage is ranked nineteenth with a MS of 3.85, followed by image improvement and public relations ranked twentieth and twenty first respectively, housekeeping, and sales related consideration / post project service.

Reduction of liability risk / Safety (occupational), site management, and middle management have MSs > 2.60 ≤ 3.40, which indicates they are between less than important to important / important.

Table 4: Importance of 26 aspects of project performance to clients.

Aspect	Response (%)							
	Unsure	Not important	Less than important	Important	More than important	Very important	MS	Rank
Quality	2.0	4.1	0.0	2.0	8.2	83.7	5.00	1
Time performance	2.0	0.0	0.0	8.2	16.3	73.5	4.48	2=
Worker skills	2.0	0.0	0.0	6.1	28.6	63.3	4.48	2=
Communication	2.0	2.0	6.1	4.1	28.6	61.2	4.46	4
Project administration	2.0	0.0	0.0	14.3	30.6	53.1	4.30	5
Health (occupational)	2.0	0.0	4.1	16.3	18.4	59.2	4.26	6
Plant & equipment condition	2.0	0.0	0.0	10.2	38.8	46.9	4.20	7
Site enclosure	2.0	0.0	6.1	8.2	36.7	46.9	4.18	8
Cost savings / Remaining within budget	2.0	4.1	4.1	16.3	22.4	51	4.06	9
Material waste	2.0	2.0	4.1	20.4	28.6	42.9	4.00	10
Procurement system	6.1	2.0	2.0	16.3	24.5	48.9	3.97	11=
Worker attire	2.0	2.0	6.1	16.3	32.7	40.8	3.97	11=
Facilities (change rooms, toilets, etc.)	2.0	0.0	6.1	24.5	26.5	40.8	3.95	13=

Site offices	2.0	0.0	4.1	12.2	44.9	36.7	3.95	13=
Own environment consciousness	4.1	2.0	6.1	14.2	30.6	42.9	3.93	15
Industrial relations	4.1	0.0	2.0	26.5	32.6	34.7	3.87	16=
Relations with site neighbours	4.1	2.0	4.1	20.4	30.6	38.8	3.87	16=
Storage	4.1	0.0	6.1	18.4	36.7	34.7	3.87	16=
Project signage	4.1	6.1	2.0	16.3	30.6	40.8	3.85	19
Image improvement	4.1	2.0	6.1	16.3	44.9	26.5	3.76	20
Public relations	2.0	0.0	10.2	26.5	20.4	36.7	3.65	21
House keeping	4.1	2.0	12.2	22.4	28.6	30.6	3.61	22
Sales related consideration / Post project service	6.1	0.0	4.2	30.6	40.8	18.4	3.44	23
Reduction of liability risk / Safety (occupational)	2.0	0.0	4.1	10.2	20.4	42.9	3.34	24
Site management	9.1	8.2	10.1	27.3	15.1	27.3	2.91	25
Middle management	8.4	10.0	18.2	33.1	17.8	12.5	2.82	26

4. Discussion

The importance of seven established systems in project implementation setup highlights the importance of site management, which is responsible for managing the physical construction process and activities, including the respective resources. Construction projects occur in the built environment and therefore, are visible to the public and subject to scrutiny by a range of stakeholders. The importance of communication plan highlights the relevance of keeping the respective internal and external publics informed, which in turn impacts on image. The public relations function is responsible for public relations, keeping the internal and external publics informed, and therefore impacts and is consequently a major contributor to and exerts influence on image. However, given that projects occur in the built environment, the public relations function cannot solely be a centralised function, and site management should be conscious and mindful of their capacity to optimise public relations and impact positively on image. Company policies impact on both the internal and external publics and should first exist, and then address the necessary project parameters such as the environment, H&S, and quality, and resources, and be appropriate, as policy informs the culture, commitment, and approach of an organisation relative to the parameters and resources.

The effectiveness of six environmental pollution control instruments highlights the importance of EMPs, consideration of the environment, compliance with statutory requirements, the impact of construction work on the environment, and behaviour relative to managing waste, including the generation thereof. The behaviour of contractors, including actions and interventions, impacts on both the internal and external publics, and therefore, image.

The rating of seven aspects of project implementation highlights the role of a range of aspects in project performance, and therefore image. These aspects require a multi-stakeholder approach and contributions to projects, as ultimately the industry's image, not just that of projects is impacted. Political leadership with respect to the industry, not just projects, is imperative, and requires interventions to enhance performance, and subsequently the image. Procurements systems should be appropriate, including conditions of contracts, and contract administration should be optimum on the part of the respective stakeholders to optimise performance and mitigate disputes, which in turn will contribute to optimising the image of the industry. Contractor productivity and performance relative to the project parameters are obviously critical in terms of meeting clients' requirements, and thus optimising the image of contractors and that of the industry.

The importance of 26 aspects of project performance to clients further highlights the multi-dimensional nature of aspects and interventions relative to the image of contractors and the industry. The reality is that all stakeholders contribute to performance on projects commencing with Stage 1 'project initiation and briefing'. Clients' and designers' decisions and interventions impact on the design, procurement, and construction processes, in addition to contractors' decisions and interventions impact during procurement and construction. Therefore, all project systems and plans should be multistakeholder in nature.

5. Conclusions

In conclusion, the negative image of the construction industry is attributed to irresponsible industry role players' behaviour. However, limited skills capacity coupled with political interference in the implementation of projects is a problem in the construction industry. While some projects, by their nature, attract political influence, this should not extend to project planning, and implementation.

Regarding best practices, there is no instrument to adequately regulate the industry in terms of continuous performance, thus identifying defaulters and barring them from any practice. The existing controls are only based on initial evaluation and contractor upgrades, but no performance evaluation is based on best practices. The inception of a regulatory institution such as the Engineering Registration Board only becomes a tool when there is clear ethical violation of the code of ethics that regulates registered members.

The construction industry lacks an established performance regulatory system in line with other sectors; hence role players still observe the construction industry as a sector where stakeholder management is not vital to the success of projects. In conclusion, relative to the statement of the problem, the impact of project performance on the image of the construction industry in Botswana is influenced by a lack of accountability from both role players, and industry stakeholders. Despite the research findings relative to the perceived impact of environmental control and compliance, the Botswana government is part of the global world and has ratified international obligations with respect to sustainable development. Twenty-first century construction industry managers are therefore required to be socially responsible for the sector's action and possible environmental impact.

Ineffective regulation of industry operators and a lack of skilled project managers remain a critical skills' gap area to ensure successful projects.

The respondents' level of education and authority on projects provide confidence in terms of the validity of the findings.

6. Recommendations

The results and findings relative to the behaviour of the role players point to a need for a structured integrity restoration process from both the regulator and the operators. The need for a paradigm shift to change the curricula to develop a team of new construction managers who will perceive the construction industry as commercial sectors of the economy as opposed to the current view that the sector is not progressive. The construction industry operators need to become customer oriented, and to achieve a positive image of the construction industry, the sector requires a continuous development programme. A further consideration is to incorporate environmental concerns into all stages of project planning and design to avoid or minimise negative impacts and realise the potential benefits.

There is a need to review the 'Factories Act CAP 44: 01 of 1979' to factor in the current industry challenges. Given the ineffectiveness of the Act, despite other established controls, there is a need to have a specific sector Act to regulate the safety, health, and environmental operations in the construction industry. The construction industry in Botswana needs to embrace the culture of capacity building within the sector, and support research and development of the industry. Furthermore, studies or research can be undertaken with respect to the assessment of ethical disparities between the construction industry, and other commercial aligned entities or the effectiveness of the construction industry regulatory systems in Botswana.

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The Future of Malls: Examining the Malls Closure and How This Space May Be Reutilized?

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Abstract

Malls have been experiencing a gradual decline in popularity for some years now. The decline in popularity of brick-and-mortar retail, and malls specifically, may not have been widely predicted with the advent of the internet, but it was certainly foreseen once online shopping began to rapidly grow in popularity. Free shipping and returns on most products accelerated the decline, whereas the COVID-19 pandemic further expanded this change. This research aims to delve into how these malls might be reused, revitalized, and reincorporated as an anchor in the community. Therefore, interviews with residents and professionals have been conducted to evaluate malls conversion and revitalization. The results of the interviews showed that traditional market research should still be pursued, however inexpensive means of gathering data, like the use of resident surveys, can be very effective in understanding the needs of a community. Also, local government can play a very positive role in the planning and development of a mall revitalization if they are proactive and move the effort along. Moreover, the findings highlight the importance of placemaking, anchor store tenant procurement, and diversity as critical in developing an enticing retail experience. The research results practically contribute to the industry and would be beneficial for mall owners and developers.

Keywords
Malls, Reutilization, Case Study, Mixed-use, Retail.

1. Introduction

Extensive research and data collection has been performed in the recent years on the current state of retail in the United States (US), both online and brick-and-mortar, and its impacts on malls in the US. E-commerce sales have been surging year after year, slowly eating into the brick-and-mortar retail market. In 2001, the e-commerce made up less than 1% of total retail sales. In 2020, it made up more than 16% (Census Bureau, 2020). Revenue is projected to be nearly $1 Trillion by 2022 and is expected to show an annual growth rate of roughly 15%. To put it into perspective, there were 25 million Amazon users in 2013. That number has increased to 124 million in 2019 (Statista, 2019). Conversely, department store revenue has been slowly declining year after year. This decline in sales has directly resulted in the closures and bankruptcies of large retailers across the US. As of 2020, there were about 6,000 department stores in the US, and that number is expected to decline by roughly 2,000 by 2025 (Census Bureau, 2020). Twenty five percent (25%) of malls are expected to shut down within 5 years (Coresight Analysis, 2020). Many of these malls are already dead or dying. A dead mall is a shopping mall with a high vacancy rate and/or lower consumer traffic level. These dying malls have lost anchor stores to closure or bankruptcy, followed by smaller chains, resulting in growing vacancies and fewer customers. The study by Amos (2020) shows that from 1980 to 2004 pedestrian mall closures were rampant. Investors began purchasing these malls and developing them into mixed-use spaces, intending to take advantage of the already existing open spaces. Amos (2020) also highlighted that part of the success of pedestrian mall revitalization was their active use of the open space. Successfully revitalized pedestrian malls hosted 6-10 events in these spaces each month. These events drew in different demographics and raised interest in visiting these malls significantly. This greatly increased foot traffic had a direct positive impact on stores revenues.

Mixed-use development is the most viable development option for many, but certainly not all, dead or dying malls. The structure of the mall may be renovated using adaptive use to reduce costs, architectural and cosmetic renovations should be made, and this adaptation should work to create open indoor and outdoor spaces. The overall objective of the development is a place where a resident can age in place, and all the amenities are available so they may work and play in a single location (Hare, 2017). Tenants offering unique experiences for adults and children will function as the retail anchor stores and bring in foot traffic that will make the necessary brick-and-mortar retail stores profitable. Free entertainment like weekly events, playgrounds, waterpark areas, and lawn games will also work effectively to bring in customers who will stay for hours and come repeatedly. Creating residential space for residents of all ages, especially demographics that would previously not have access to the mixed-use space, would also bring in more customers. The case studies conducted by the National Association of Realtors Research Group in 2020 revealed that a few major objectives should be targeted to successfully revitalize a mall. Public financial support was critical to initiate these revitalization projects. A mix of financing sources is helpful to assure the development can avoid or endure economic risks. Community buy-in for the project will greatly assist in moving the project forward in the early stages. Even though there is some research (Moccia, 2012; Dunham - Jones & Williamson, 2017). in the literature on vacant malls re-use, there are no recent studies considering the current status of the U.S. economy after COVID-19. Therefore, this study aims to determine viable options to reutilize these spaces in the current situation. The research objectives are as follows:

1. Understand the cause of Mall failures.
2. Develop a list of factors that should be considered by any Mall Developer or Owner prior to Mall conversion.
3. Survey users and residents to get local opinion on mall revitalization ideas. Interview Industry leaders to gain further insight on revitalization ideas.
4. Provide guidelines to any Owner or Developer who wishes to pursue this path.

2. Methodology

This study primarily utilized qualitative research in the form of descriptive surveys of the residents of Chambersburg, PA concerning the "dead" Chambersburg Mall and interviews with industry leaders. The residents survey was developed in Qualtrics and distributed virtually through three Chambersburg Facebook groups. Since it was not possible to pick specific residents from the Facebook groups hence no sampling method was used and invitations were sent to all registered participants in the three Facebook groups. The respondents were asked nine questions related to their usage attitude toward Chambersburg Mall. These questions are listed in Appendix A.

Interviews were performed with leaders in the industries associated with the revitalization of existing malls: Real Estate Development, Architecture, Engineering, Construction, and Local Government. The overall objective of these interviews was to gain insight from those working on these projects regularly and gain their perspective on how to execute these projects successfully. An additional objective was to find industry leaders associated with the Chambersburg mall for interviews so their feedback could be linked with the residents' survey performed. Table 1 shows the details of the interviewees.

Table 1. Expert Interviewees Detail

No.	Position	Company Type
1	President and CEO	Architecture/Engineering
2	Deputy Director	Local Government
3	Project Manager	Construction Contractor
4	Township Engineer	Local Government
5	Executive VP of Leasing Operations and Marketing	Developer
6	Owner, CEO	Construction Contractor

3. Results

3. 1 Resident Survey Results

The resident survey was directed toward the residents of Chambersburg, PA, and surrounding areas via Facebook groups. The intent was to gain an understanding of resident sentiment toward the mall, thoughts on how it could be improved, and gauge public interest in the mall in general. The total number of members in all three groups are 40,700. A total of 958 responses were recorded from October 14th to October 18th, 2022, which resulted in a response rate of 2.4%. Though the response rate is very low but the number of respondents (i.e. 958) are significant to draw reasonable conclusions. The important findings are shown in the following section.

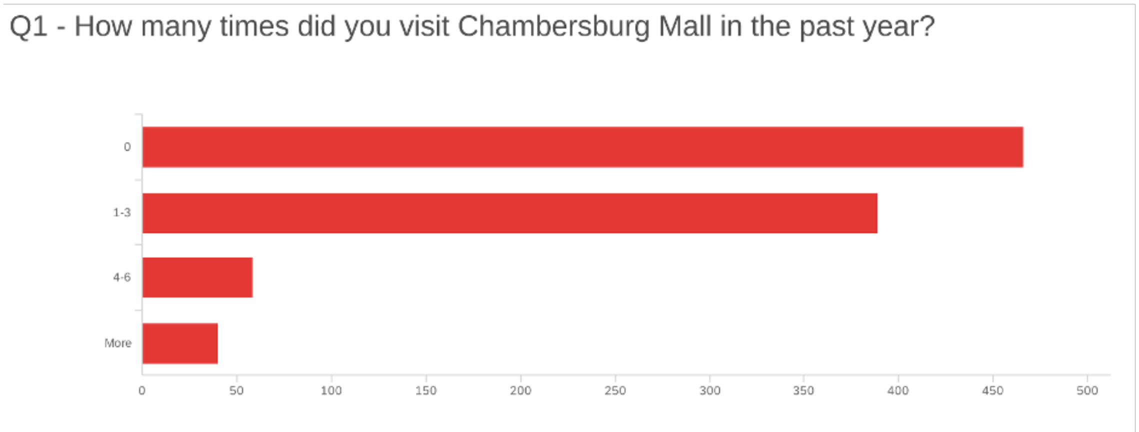

Fig. 1. The Frequency of Resident's Visit to the Mall

The result of the survey revealed that nearly 50% of the participants had not visited the mall in the last year, and over 30% had only visited 1-3 times. Accordingly, we may say that mall foot traffic was extremely low.

Fig. 2. The mall store categories favored by the residents.

The participants selected their top 4 stores as restaurants, active entertainment (trampoline park, axe throwing, rope course, etc.), a movie theater, and distilleries or breweries, and stated that they desire to see an open space established for performances, theater, seasonal events, concerts, etc.

The results of remaining questions are as follows: 83% of participants stated that they see the size of the Chambersburg Mall as adequate and would not change it. It could be inferred from this response that most residents would rather see the current mall footprint full of shops again, rather than see a reduction in size and an equal reduction in available retail stores. This inference could be made based off the information provided in the responses to the next question, where 82% of participants would rather see the mall partially or fully renovated and replete with retail shops rather than see it remain the same or demolished entirely. Over 80% stated mall cleanliness was critical, and over 75% wish to see both an interior and exterior makeover.

3.2 Industry Expert Interview Result

Industry leaders in multiple industries related to mall restoration were targeted for interviews. Companies that have been directly involved with mall revitalization, restoration, or repurposing projects were targeted for interviews, as team members from these companies will be able to answer interview questions from their own experience. In total, six interviews were conducted, two with construction contractors, two with local government employees, one with an AE firm, and one with an owner/developer. The interviews with each leader were structured in nature. Thirteen interview questions were put forth. Table 2 summarizes the key answers of the interviewees. Their responses were discussed in more detail in the discussion section.

Table 2. Expert Interview Results

No	Question	Key Answers
1	What is motivating you or your company to renovate or revitalize existing malls?	Diversity in the portfolio, county government's support
2	What financial vehicles do you use typically to pursue these revitalization projects?	Tax increment financing of local government, private lenders
3	Do you pursue incentives with state/county/city governments? What kind of incentives are available?	Tax credits, state and federal programs
4	What is the process, and how long does it take, to line up these financial vehicles?	It may take years to line up financial vehicles or incentives available from different levels of government.
5	When examining mall properties and performing a site visit, what do you look for to determine whether it is viable or not viable to revitalize from a construction perspective?	The structure, change in design, Compliance with current code.
6	During a review of the existing space, what issues do you look for that may increase cost of the project throughout each phase (development, design, construction, occupancy)?	The reason causing the property to fail, tenants, other retails surrounding.
7	What are all the components of your market research, and which do you examine the most to determine viability of a project?	Fire Suppression, ADA, and HAZMAT abatement requirements.
8	What was your most successful mall revitalization project and what made it successful?	Mixed-use development.
9	What is a single aspect of renovation you find leads to a successful mall revitalization?	Intelligent placemaking
10	What single aspect of renovation you found most challenging?	Difficult existing conditions e.g., misplaced utilities, etc.
11	Do you include the Construction Contractor in your design phase of the mall revitalization?	Usually, no.
12	How do you determine what stores or companies will occupy the renovated mall space	Depends on the market, customers and the space.
13	How do you determine layout and locations of these new stores throughout the space?	Maximizing leasable area, access for loading, servicing, and providing convenient parking.

4. Discussion

As a result of the interviews with industry professionals, we have got an abundance of information and insight. Based on these interviews, four main items for re-utilization came out: mixed-use development, public input and market research, placemaking, and consumer experience. Mixed-use development is the future means of reaching the public and enticing them to visit brick-and-mortar retail stores. During the design phase, it is helpful to have the construction contractor on board, if possible, to provide insight regarding the renovation work and suggestions for value engineering. Mixed-use developments can be any combination of development types, and their planning and design are often driven by public input and market research. Tools like polls, town hall meetings, public involvement with planning and design charrettes, and public involvement with the design phase can all have huge benefits. Resident feedback can guide the amount of residential housing, the size of office space, the types of goods and services available, and the overall layout of a new real estate development. Considering this development will be used mostly by these people, it is usually extremely helpful to understand their wants, needs, and interests during the planning phase. Placemaking, on the other hand, is creating places and focusing on the transformation of public places to strengthen the connection between people and those places (Wyckoff, 2014). Architects and developers have begun utilizing techniques in building and site design to create spaces where people want to congregate at. The places are for sitting, playing, walking, meeting, eating, and drinking. These places may be the site for recurring or seasonal events, performances, and theater. Concerning mall revitalization, placemaking could quite literally be the reshaping of the existing building to create courtyards, meeting areas, walkways, or "main street" style storefronts. Adaptive reuse, or the reshaping of an existing building, can be employed in these cases to make a new place.

Moreover, a significant pull for consumers and residents currently is experience-based, as opposed to product-based, consumption. Consumers are less interested in shopping for products and are more interested in spending their money on experiences, whether they be as large and unique as skydiving or as mundane as axe throwing. Consumers are craving experience and a variety of this. Mall revitalization projects must understand that there are many more options for a retail tenant than there were twenty years ago. Breweries, and distilleries, experiences based entertainment like climbing gyms, axe throwing, ropes courses, and escape rooms, dining experiences like pop-up restaurants, food trucks, and experimental kitchens are becoming popular among the consumers.

Financial vehicles are typically public and private institutions or Real Estate Investment Trusts (REITS). Financial incentives are rare but must be pursued if available. During an interview, one participant reported that for a retail restoration project they had undertaken, a private lender had provided initial funding, while the city had later provided additional funding to offset cost escalation resulting from COVID-related factors and changes to the project. On the other hand, as the interviewees highlighted, bringing an existing building up to code (MEP, Fire Suppression, ADA), abating hazardous materials, and addressing other unforeseen conditions can have significant cost impacts on any revitalization project. One participant noted that examining the structure itself and understanding how the developer or AE firm wished to change the shape of the structure was critical. Depending on the desire to demolish, add or change the shape, it may have a significant impact on construction costs, including extensive structural work.

Moreover, finding the right anchor stores, and the right placement for all tenants in a given space is critical to the success of the project. Accessibility must also be considered, especially if the project is a mixed-use development and senior living is included in this project. The overall profile of a space and a project must be understood as well. Placemaking plays a major role in making a renovation or revitalization successful, as many customers today see open space as extremely desirable as opposed to crowded corridors.

Lastly, an observation made during the interviews with the two local government officials was the action taken by each entity to pursue a mall revitalization project. One of the interviewees noted that it was in the township's best interest, and desired by the community, to renovate and revitalize the Chambersburg Mall, but the township had not taken any action to determine how this project would happen. They had not coordinated with the building owner to determine the company's goals with the mall and had not hired an AE Firm to perform a planning charrette. Alternatively, one of the other participants noted that the government had been proactive in determining the future of another mall, the Security Square Mall. The county had conducted multiple town hall meetings to confirm the public's desire to revitalize the space, had hired an AE to perform a planning and design charrette which provided multiple development design options to be put to the public vote, and had run multiple meetings concluding the planning phase and discussing the plans to start design on the agreed upon concept. It is acknowledged that each entity is dealing with different obstacles of varying complexity, however, one government entity took a proactive approach to redevelop the area and is moving forward successfully.

In conclusion, the interviews with industry professionals have shed light on several key factors that are crucial to the success of mall revitalization projects. Mixed-use development, public input and market research, placemaking, and consumer experience have emerged as the main items for re-utilization. Developers should consider engaging the construction contractor during the design phase to provide insights and suggestions for value engineering. Public involvement through polls, town hall meetings, and design charrettes can also be invaluable. Placemaking can help transform public places and create spaces where people want to congregate, while experience-based consumption is becoming increasingly popular among consumers. Financial incentives are rare but should be pursued if available, while finding the right anchor stores and tenants and ensuring accessibility are critical to project success. Finally, proactive government action and coordination with building owners and AE firms can help overcome obstacles and lead to successful revitalization projects.

5. Conclusions and Recommendations

This research aimed to discover the current situation of malls and the re-utilization of these spaces through resident surveys and expert interviews. The result showed the insights for these vacant malls to reutilize and regain public use and highlighted the importance of mixed-use development, public input and market research, placemaking, and consumer experience. Some important conclusions are as follows:

- Local Government plays a significant role in initiating these projects.
- Examine community sentiment closely and keep them involved throughout the process. Full buy-in is critical.
- Utilize low-cost methods of gathering data in early planning phase to gain good understanding of community wants/needs.
- Take into consideration all takeaways noted in Industry Leader Interviews, resident survey sections.

Following are some recommendations:

- Examine how online resident surveys can be better employed during planning phases of these developments.
- Better education for local governments concerning the processes of processes of real estate development, design, and construction.
- New and unique commercial options for tenants be continually monitored to best understand the current wants and needs of the public. Change must not lag decades behind.

This research also has some limitations. First, the conclusions are drawn from a single case study and may not be fully applicable to other malls. Hence it is recommended to conduct more such case studies to validate these conclusions. It is also difficult to determine the success rate of using these four above-mentioned factors as drivers for development until many projects are completed in this fashion, and even of those completed projects, there will be many variables that would impact the success of the project that can neither be measured nor controlled. This is the difficulty and risk with development in general. This approach must be employed, and projects that use these factors as drivers for development must then in turn become case studies. We recommend that future studies utilize a quantitative method to validate this research findings.

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Appendix A: Residents Survey

1. How many times did you visit Chambersburg Mall in the past year?
2. What stores would you like to see open in Chambersburg Mall? Select all that apply:
3. Would an open/performance space with events, concerts, access to eateries, etc. at this mall entice you to visit?
4. How important is mall cleanliness to you? 1 Least, 5 most.
5. Would an interior design renovation entice you to visit?
6. Would an exterior renovation entice you to visit?
7. What are your thoughts on mall size?
8. What recommendations do you have to entice visitors to this mall?
9. Ultimately, would you like to see the mall: Remain the same, be fully or partially renovated to include any of the new shops listed above, Be demolished.

Green Retrofitting of Existing Buildings in South Africa

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Abstract
Existing buildings account for a large consumption of energy and greenhouse gas emissions. However, studies have noted that the conversion of existing buildings into green buildings has great potential to conserve energy and reduce these greenhouse gas emissions. Based on this knowledge, this study assessed the green retrofitting features employed in existing buildings and the drivers of the use of these features in South Africa. The study was conducted among participants with expertise in green construction through a questionnaire survey. The data gathered were analysed using a mean score, Kendall's coefficient of concordance, chi-square, and exploratory factor analysis. The study found that the use of movement sensors to control electricity usage is a common feature in the country. Furthermore, the use of green retrofitting is driven by five major group of factors, vis; (1) economic growth, (2) occupants' expectations and satisfaction, (3) environmental sustainability, (4) return on investment, and (5) government support. The findings also offer a theoretical contribution to the existing green construction discourse from the perspective of existing buildings in South Africa.

Keywords Green building, Green retrofit, Sustainable construction, Sustainability

1. Introduction
The building sector plays a vital role in developing countries economic growth and job creation (Fenske, 2019). However, despite its significance, the building sector has been heavily associated with greenhouse gas emissions, environmental degradation, global warming and energy consumption (Doan *et al.*, 2017; Okorafor *et al.*, 2020). Approximately 10% of all global energy supply occurs during building materials manufacturing (Burdett *et al.*, 2011). The United Nations environmental programme reports that the built environment contributes approximately 40% to global energy consumption and 36% to greenhouse emissions (Terblanche, 2019). Also, rapid urbanisation has been seen to cause pressure on energy, resources and the environment (Baldwin *et al.*, 2018), and recently, developing countries have become known for their rapid urbanisation (Aghimien *et al.*, 2022; Terblanche, 2019). To this end, the International Energy Agency (2008) has predicted an increase in the share of urban energy demand to 70% and CO_2 emissions to 76%.

Green retrofitting has been proposed as a viable option to address this issue of the unsustainable nature of the built environment. The term retrofitting, according to Ismail and Rogerson (2016:3), "is an attempt at rectifying environmental degradation and improving upon the existence of resource-intensive and efficient systems which inevitably exert negative environmental consequences". Aigbavboa *et al.* (2019:2) define building retrofit as "the addition and utilisation of new technologies and features to enhance their effectiveness and efficiency". Therefore, green retrofitting can be described as a sustainable approach to enhancing the energy resource efficiency of existing buildings (Li *et al.*, 2020). The conversion of existing buildings to green buildings can assist in conserving energy and reducing the global emission of carbon gas (Lueng, 2018).

Like other developing countries, South Africa is experiencing rapid urbanisation, with more than 60% of the country's population moving into cities (United Nations, 2020). Expectedly, this influx of people into cities has put significant stress on the available infrastructure and has also resulted in intense pressure on energy resources and the environment (Baldwin *et al.*, 2018). Thus, it has become a challenge for the government to meet the energy demand of the large population (Aigbavboa *et al.*, 2019). According to McClintock *et al.* (2017), existing buildings consume the highest amount of energy within the building sector. Therefore, green retrofitting of the existing structure has been proposed as an effective tool to mitigate the deteriorating environment, attain sustainability, and improve energy resource efficiency (Deng *et al.*, 2019; Li *et al.*, 2020). However, in South Africa, not much attention has been paid to greening existing buildings (Aghimien *et al.*, 2018). Only a few studies have explored the green retrofitting of existing buildings in the country. Thus, the need for empirical evidence that will encourage the transformation of existing buildings into more sustainable dwellings and reduce the negative impact of these buildings on the environment is important. To this end, this study assessed the green retrofitting features employed in existing buildings and the drivers of the use of these features in South Africa. Subsequent parts of the paper include a review of extant literature, methodology, findings and conclusions drawn from the study's results.

2. Green Retrofitting of Existing Buildings

It is accepted that 21st-century urban areas must be greener and more intelligent; thus, advancing maintainable urban areas has become a central point of contention for some diverse countries worldwide. The idea of sustainability is a broad worldwide issue, including different interrelated examinations of individuals, the climate and society (Berardi *et al.*, 2013). To this end, the Green Building Council of South Africa (GBCSA) was formed in 2007. The GBCSA is aimed at developing green building solutions to drive the revolution of the South African construction industry towards sustainability. The council advocates for solutions and tools that enable the design, construction and operation of all buildings in an environmentally sustainable manner. It provides certification of buildings using diverse rating tools such as Green Star, Net Zero, EDGE among others. The council further encourages a new approach to designing and building by rewarding best practices and excellence.

Unfortunately, many existing structures have been noted to be energy and water-wasteful (Alam *et al.*, 2019). By adhering to new codes, by 2050, the world structure warming and cooling energy use could be decreased by about 46% when contrasted with 2005 (Ürge-Vorsatz and Herrero, 2012). Also, by consolidating the presently accepted procedures in building plans, developments, and activities, through cutting-edge retrofits, energy and water wastage can decrease by up to 40%. Hence, retrofitting existing structures is the way into a supportable future since the current structures, which seem to be unstainable at the moment, will be with us as long as possible (Alam *et al.*, 2019).

Several drivers can play a significant role in achieving the effective implementation of green retrofitting. For instance, the attitude towards energy savings, awareness of sustainable measures, income, age, and education have been noted as some factors (Dunkelberg and Steib 2013). According to Organ *et al.* (2013), internal and external factors motivate green building retrofit. The external factors can be financial rewards, while the internal factors are based on individual needs, expectations, and satisfaction. Studies have also noted the role of government policies and legislation in driving green retrofitting of existing buildings (Ampratwum *et al.*, 2019). Policy guidance and government can motivate building owners to implement green retrofit (Li *et al.*, 2020). In December 2015, South Africa's National Treasury released a draft carbon tax bill. The carbon tax aims to influence change in how firms operate, providing incentives to those moving towards cleaner technologies (Aigbavboa *et al.*, 2017; Bohlmann *et al.*, 2016). Also, enforcing these policies and legislations is crucial to successfully implementing these green concepts (Powmya and Abidin, 2014). The availability of administrative and authoritative structures puts focus on all significant development partners to either embrace the new concept or face the consequences of non-adoption. Administrative and authoritative prerequisites are powerful and compelling in both driving change and bringing issues to light (Ampratwum *et al.*, 2019). Also, Cheng *et al.* (2019) noted that government provision of economic subsidies, tax preferences, discounts on loans' interest rates, technical support for green retrofitting initiatives and direct rewards could be a positive driver of green retrofitting. Lueng (2018) also emphasised the significance of the government's financial support in influencing green building.

The expectations of occupants of an existing building can also be a crucial driver to the green retrofitting of such a building. According to Liang *et al.* (2016), the owners and occupants are key players in establishing green retrofit. Occupants have a direct impact on the energy use of the building through expectations of indoor air quality and visual and acoustic comfort, which determine their satisfaction with the building (Leng, 2018). Clearly, the satisfaction of these occupants is important. Ampratwum *et al.* (2019) noted that when existing buildings are green-retrofitted, they become energy-effective and less contaminating, giving a more advantageous climate to their occupants. More so, green structures save energy and water and add to the occupant's wellbeing.

Buildings are considered an investment for many owners, and the main concern is risk and rate of return. Greening existing buildings gives building owners the possibility of impressive future returns on their structures. According to Windapo (2014), investors seek assurance that buildings are green star rated to avoid being unable to sell or lease their building in the future. Green structures have a serious market advantage as designers and investors have noted that green structures command more noteworthy market interest in readiness to pay than conventional structures (Aliagha *et al.*, 2018). Retrofitting a structure is frequently more affordable than destroying and rebuilding new ones. Furthermore, since no destruction is done or as the development time frame is decreased, the financing cost is diminished (Jagarajan *et al.*, 2017). Other significant drivers are the conservation of energy and the natural environment (Jagarajan *et al.*, 2017), the need to combat global warming (Lueng, 2018), enhancing the sustainability of existing buildings (Jagarajan *et al.*, 2017; Li *et al.*, 2020) and potential growth on the economy (Saladin and Turok 2013).

3. Research Method

The study is quantitative and employs a structured questionnaire to explore the green retrofitting of existing buildings in South Africa. The use of questionnaires was premised on the ability of the instrument to reach a larger group of respondents within a short time (Tan, 2011). The study employed a purposive and snowball sampling approach to gather data from green building experts. Purposive sampling was first used to identify some professionals that have worked on green buildings. However, because it was difficult to determine the total number of green building experts at the time of conducting the research, a snowball approach was then employed to reach out to more experts through a referral from those initially identified. Based on the approach adopted, 123 usable samples were derived and considered fit for data analysis in the study. The questionnaire was designed in sections, where the first section sought answers to specific demographic questions. The second section assessed some of the green retrofitting features adopted on a 5-point Likert scale, with one being very low usage and five being very high. The third section of the questionnaire explored the drivers of implementing green retrofitting in existing buildings using a 5-point agreement scale, with 1 being strongly disagree and 5 being strongly agree.

The analysis of the data gathered on the respondents' background information was done using frequency (f) and percentage (%). The reliability of the questions in sections two and three was tested using the Cronbach alpha (α) test with a cut-off of 0.7. To rank the factors in both sections, the mean score ($\bar{X}$) was employed. Furthermore, Kendall's coefficient of concordance (W) and chi-square (χ^2) were adopted to affirm the level of agreement between respondents in the ranking of the variables in the two sections. The choice of employing χ^2 is premised on its suitability in assessing variables higher than seven (Siegel and Castellan, 1988). The data from section three was further explored using exploratory factor analysis (EFA). EFA is suitable for regrouping many variables into more describable subscales using the latent similarity between variables (Field, 2000). To conduct EFA, studies have encouraged a large sample (Norris and Lecavalier, 2010; Tabachnick and Fidell, 2013), a good Kaiser–Meyer–Olkin (KMO), and a significant p-value for the Bartlett test of sphericity (BTS) (Field, 2000; Preacher and MacCallum, 2002). The sample size, KMO and BTS derived in the study were considered adequate for EFA to be conducted.

4. Findings and Discussion

4.1 Background information

The analysis of the background information of the respondents revealed a spread of respondents from consulting (f = 60), contracting (f = 15), property investment (f = 26) and public sector (f = 22). These respondents possess bachelor's degrees (f = 66), master's degrees (f = 20) and diplomas (f = 24). They comprise green-star engineers (f = 15), green consultants (f = 36), facilities managers (f = 17), property developers (f = 18), and construction project managers (f = 37). Also, many of these respondents (f = 41) have between one to five years of working experience, while the remaining 82 respondents have above five years of experience within the South African built environment. The findings from this background information show that the respondents for the study are well equipped both academically and in experience to give logical answers to the questions of the research.

4.2 Green retrofitting features used in existing buildings in South Africa

The reliability test revealed an α-value of 0.782 for the green retrofitting features assessed in the study area. This implies that the instrument used for this section is reliable as the derived α is higher than the 0.7 cut-off. The result in Table 1 shows that the respondents for the study noted that the use of movement sensors ($\bar{X}$ = 4.49) and the installation of water tanks for water preservation ($\bar{X}$ = 4.37) are the two most commonly used features of green retrofitting in the study area. The use of cool roofs ($\bar{X}$ = 4.34), grey water recycling ($\bar{X}$ = 4.34) and replacing electrical fixtures ($\bar{X}$ = 4.32) are also gaining prominence in the study area. On the other hand, using materials that are less volatile appeared as the least features ($\bar{X}$ = 3.18) and requires further attention in the quest for a green environment.

The standard deviation (SD) of all the assessed variables is below 1.0, thus implying that there is no deviation in the $\bar{X}$-values of these variables as rated by the respondents. Further analysis using Kendall's W gave a value of 0.45, below the average of 0.5. However, the calculated χ^2 (340.48) is greater than the critical χ^2 (26.76) derived from the statistical table, thus implying that the respondents' ranking of the green retrofitting features is related to each other within the groups, and no disparity exists.

Table 1: Green retrofitting features of existing buildings

Green retrofitting features	$\bar{X}$	SD	Rank
The use of movement sensors	4.49	0.502	1
Installation tanks collecting rainwater for water preservation	4.37	0.760	2
The use of a cool roof for minimising the roof surface temperature	4.34	0.675	3

Grey water recycling systems	4.34	0.756	4
Replacing electrical fixture	4.32	0.577	5
The use of daylight control measures	4.20	0.746	6
Installation of louvers to minimise heat gain	4.20	0.757	7
Installing mechanical ventilation of systems	4.11	0.749	8
Insulation of internal and external wall cavities	4.08	0.609	9
Modifying existing windows	3.86	0.793	10
Replacing fan coils with heat pumps	3.45	0.898	11
The use of painting, carpets, sealants, glues, and adhesives with low volatility	3.18	0.869	12
Kendall's *W*	0.452		
χ^2	340.48		
χ^2 – Critical values from the statistical table (p = 0.05)	26.76		
Df	11		
Sig.	0.000		

4.3 Drivers of green retrofitting of existing buildings in South Africa

The reliability test conducted revealed an α-value of 0.812 for the drivers of green retrofitting in the study area. This implies that the instrument used for this section is reliable as the derived α is higher than the 0.7 cut-off. The result in Table 2 shows that the most significant drivers, according to the rating of the respondents, are the need to combat global warming ($\bar{X}$ = 4.54), government financial support ($\bar{X}$ = 4.39), conservation of the natural environment ($\bar{X}$ = 4.38), future competitiveness for investors ($\bar{X}$ = 4.37), and expectations of occupants ($\bar{X}$ = 4.31). The idea that retrofitting cost lesser than demolishing and rebuilding was rated as the least driver with a $\bar{X}$ of 3.02. The SD of all the assessed variables is below 1.0, thus implying that there is no deviation in the $\bar{X}$-values of these variables as rated by the respondents. Further analysis using Kendall's *W* gave a value of 0.58, which is above the cut-off of 0.5 set for a disparity to exist in the rating of the variables. Also, the calculated χ^2 of 659.13 is greater than the critical χ^2 (32.80) derived from the statistical table. This result shows that the ranking of the drivers of green retrofitting by the respondents is related to each other within the groups, and no disparity exists.

Table 2: Drivers of green retrofitting of existing buildings

Drivers	$\bar{X}$	**SD**	**Rank**
Need to combat global warming	4.54	0.617	1
Government financial support	4.39	0.661	2
Conservation of the natural environment	4.38	0.594	3
Future competitiveness for investors	4.37	0.812	4
Expectations of occupants	4.31	0.703	5
Satisfaction of occupants	4.24	0.682	6
Government policies and regulations	4.04	0.814	7
Conservation of energy	4.01	0.659	8
Attractive return on investment	4.00	0.810	9
Protecting investment	3.99	0.773	10
Enhancing the sustainability of existing buildings	3.97	0.557	11
Government enforcing existing legislation and policies	3.95	0.700	12
Potential growth on the economy	3.72	0.890	13
Pressure on construction stakeholders	3.44	0.925	14
Retrofitting cost lesser than demolishing and rebuilding	3.02	0.730	15
Kendall's *W*	0.557		
χ^2	659.13		
χ^2 – Critical values from the statistical table (p = 0.05)	32.80		
Df	14		
Sig.	0.000		

Considering the large number of drivers assessed (15), EFA was conducted to further reduced these drivers into a more manageable subscale, as suggested by Pallant (2011). In conducting EFA, the factorability of the data was tested using the KMO and BTS analysis. KMO revealed a value of 0.623, which is above the threshold of 0.6 for factorable data. Also, BTS was significant at a p-value of 0.000 which is in line with past submissions that the BTS value must be < 0.05 for data to be considered factorable (Tabachnick and Fidell, 2013). Following these results, the EFA was conducted on the 15 drivers using principal component analysis (PCA) with Varimax rotation. Five principal components with an eigenvalue of above one and a cumulative variance of 85.17% were derived. This implies that the 15 assessed variables account for 85.2% of the drivers of green retrofitting in the study area. The other 14.8% can be found in other variables not assessed in this current study. The result from the scree plot in Figure 1 further confirms the retaining of these five components as a clear change is visible from the fifth variable.

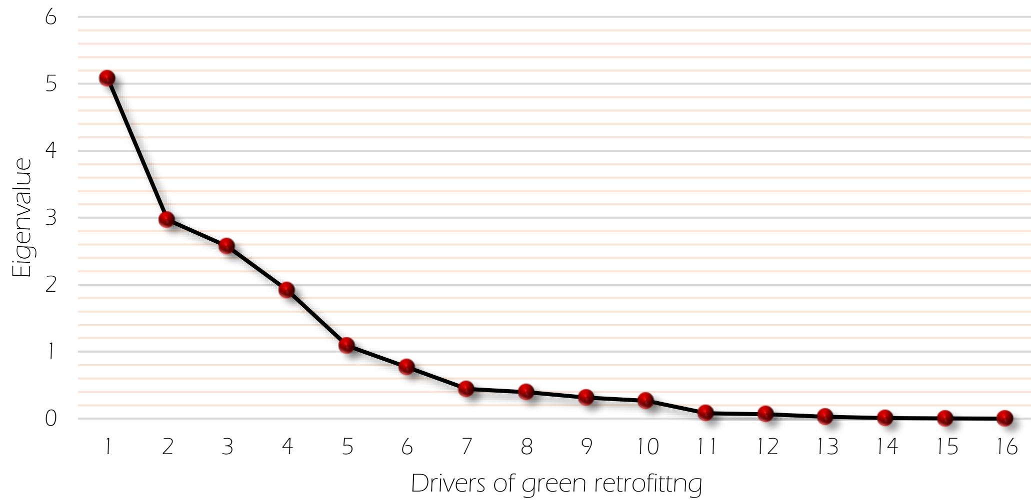

Figure 1: Scree plot

Table 3 shows the five extracted components. These components are:

Economic growth - The first principal components account for 31.7% of the total extraction and have two variables; retrofitting cost lesser than demolishing and rebuilding and the potential economic growth. This component was named economic growth drivers based on the latent similarity between these two variables.

Occupants' expectations and satisfaction - The second principal component account for 18.6% of the total extraction and has three variables. These variables are the satisfaction of occupants, expectations of occupants and pressure on construction stakeholders. This component was subsequently named occupants expectations and satisfaction based on the relatedness of the variable.

Environmental sustainability - Component three, which accounts for 16% of the total extraction, has four variables. These variables are the conservation of energy, conservation of the natural environment and enhancing the sustainability of existing buildings. The variables' similarity led to the naming of the group as environmental sustainability.

Return on investment - The fourth principal component has three variables and accounts for 12% of the total extraction. The variables in the component are future competitiveness for investors, attractive return on investment, and protecting investment and were subsequently named return on investment drivers.

Government support - The last principal components account for 6.8% of the total extraction and have three variables, vis, government policies and regulations, government enforcing existing legislation and policies, and government financial support. Since these variables are all government related, the component was subsequently named government support.

Table 3: Rotated component matric of the drivers of green retrofitting of existing buildings

	Extracted components					Communalities
Drivers	**1**	**2**	**3**	**4**	**5**	**Extraction**
Retrofitting cost lesser than demolishing and rebuilding	0.936					0.923
Potential growth in the economy	0.918					0.889
Satisfaction of occupants		0.961				0.945
Expectations of occupants		0.837				0.917
Pressure on construction stakeholders		0.692				0.724
Conservation of energy			0.907			0.901
Conservation of the natural environment			0.900			0.949
Enhancing the sustainability of existing buildings			0.698			0.837
Need to combat global warming			0.530			0.780

Future competitiveness for investors	0.911		0.923
Attractive return on investment	0.870		0.860
Protecting investment	0.661		0.802
Government policies and regulations		0.865	0.834
Government enforcing existing legislation and policies		0.803	0.893
Government financial support		0.688	0.772

4.4 Discussion of findings

The findings of the study revealed that while green retrofitting is not as common as the traditional approach in the study area, some green retrofitting features are evident. The use of movement sensors born out of the rapid technological advancement that is also influencing South Africa (Dall'Omo, 2017) was observed from the result of the study. Also, the installation of water tanks for water preservation, use of cool roofs, grey water recycling and replacing electrical fixtures with energy-efficient ones are commonly used in green retrofitting in the country. Evidently, while the perseveration of water is heavily considered, the perseveration of energy through the use of appropriate fittings is necessary. This is in support of Camhbel *et al.*'s (2014) submission that the replacement of electrical fixtures with energy-efficient light controls and green power promotes sustainable buildings. As such, Fansa and Gunatilake (2018) have suggested that movement sensors and dimmers are to be utilised to meet lighting requirements in buildings at all times.

The use of green retrofitting is driven by several factors that can be grouped into five major clusters, vis; (1) economic growth, (2) occupants' expectations and satisfaction, (3) environmental sustainability, (4) return on investment (5) government support. Studies have noted that green retrofitting can offer better value for money. Since it is easier to green retrofit than to demolish and reconstruct, some savings are made in cost and time (Jagarajan *et al.*, 2017). This can be a significant driver of the adoption and implementation of green retrofitting in some existing buildings, as indicated by the findings of this current study. Also, Liang *et al.* (2016) have earlier noted that owners and occupants are key players in establishing green retrofit. The findings of this current study support this submission as it was discovered that drivers relating to the satisfaction and expectations of the occupants and other stakeholders could significantly shape the adoption of green retrofit. Thus, building owners seeking to ensure that their occupants gain satisfaction with their buildings might have to consider using green features to retrofit their structures. This is because studies have noted that green retrofitted buildings give a better atmosphere and improve occupants' wellbeing (Ampratwum *et al.*, 2019).

Past studies have noted that the built environment is one of the biggest contributors to greenhouse emissions (Burdett *et al.*, 2011). However, it has also been noted that green retrofitting has the potential to reduce carbon emissions (Lueng, 2018). As such, it is not surprising to see experts within the study area indicating that the need to conserve energy and the natural environment and ensure the sustainability of existing buildings are essential drivers of the use of green retrofitting. All these are pointers to the fact that as the sustainability discussion grows, more green concepts will be introduced to existing buildings to make them reach the required standards. Also, it has been noted that green retrofitting of buildings offers a better return on investment for clients and a competitive market advantage (Aliagha *et al.*, 2018). The finding of this study affirms this submission as the envisaged return on investment is a key driver of green retrofit in the study area. Investors and owners of existing buildings can, therefore, take the opportunity of improving the future worth of the property by investing in green features that will yield better investment returns.

Finally, the government's role in attaining a green environment has been emphasised in past studies (Ampratwum *et al.*, 2019). This support can be in the form of financial assistance for clients seeking to implement green concepts (Cheng *et al.*, 2019), enacting of laws that support green concepts (Li *et al.*, 2020) and ensuring that measures are put in place to enforce the laws enacted (Powmya and Abidin, 2014). The findings of this current study support these past submissions as it was noted that government support is a significant driver of green retrofitting of existing buildings in South Africa.

5. Conclusion

The study set out to assess the green retrofitting features employed in existing buildings and the drivers of using these features in South Africa. Through a quantitative survey, the study concludes that while green retrofitting is just gaining recognition in the country, green retrofitting features such as the use of movement sensors, water tanks installations for water preservation, cool roofs, grey water recycling and replacement of existing electrical fixtures with energy-efficient ones are evident in the country. The drivers of green retrofit in the country can be grouped into economic growth, occupants' expectations and satisfaction, environmental sustainability, return on investment and government support. Thus, the study recommends that for green retrofit to be pervasive in South Africa, it is essential for building owners and investors to be sensitised on the economic benefits and possible return on investment they can get from employing this approach. Also, the government must be ready to push the green transformation agenda rigorously through support, policies, and legislation favouring green concepts.

The study's findings offer guidance on the use and drivers of green retrofitting to encourage the transformation of existing buildings into more sustainable dwellings. The findings also offer a theoretical contribution to the existing green construction discourse from the perspective of existing buildings in South Africa. Despite these contributions, the study's methodology limits the results. The current study adopted only a quantitative approach. Future works can employ a qualitative or mixed-method approach to get a different perspective.

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Benefits and Limitations of Crime Prevention through Environmental Design (CPTED) - A Review of Literature

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Abstract

The goal of this study is to conduct a literature review using the PRISMA protocol to examine the benefits and limitations of the CPTED approach to reducing crime. The PRISMA protocol was used to define the methodology for the literature search. The relevant keywords were graphically mapped using VOSviewer®. The keywords that were identified were then used to search for relevant articles on Engineering Village and Web of Science. For the selected publications, bibliometric and qualitative analyses were carried out. Even though the research topic has existed since the 1970s, it did not capture the attention of researchers until the 2000s. According to bibliometric analysis of research locations, the United States has been the primary focus of CPTED, followed by Australia and England. According to the secondary literature on the subject, there is growing evidence demonstrating the success of CPTED in several countries. CPTED is developing visualizations of environments as a future research direction. As new imaging technologies developed, they were used to assess the perceived vulnerability of real or proposed environments to various types of crime (such as burglary).

Keywords

CPTED Benefits, CPTED Dis-benefits, PRISMA, VOSviewer®

1. Introduction

Given the state of both local and global security, it is difficult to overstate the need of strong physical protection given the rising crime rate. If we stick to discussing burglaries, Statista (2021) stated that in 2020, there were 399.5 burglaries for every 100,000 people in the US, while in 2018, there were 376 burglaries for every 100,000 people. The FBI estimates that there were 1,117,696 burglaries in 2019, making about 16.1% of the total anticipated number of property offenses. In 2019, the anticipated $3 billion in property losses were incurred by burglary victims. An average of $2,661 was lost because of each burglary. One property crime is anticipated to occur every 4.1 seconds in 2017, while one burglary is anticipated to occur every 22.6 seconds, according to the FBI (2018). Given the figures, it is difficult to understate the need of having strong physical protection, especially when the crime is increasing quickly.

To tackle this phenomenon as of right now, the appropriate authorities have made significant financial investments in crime prevention programs using a reactive strategy. However, as rising crime rates invalidate any claims of progress, these investments have fallen short of expectations, just like they do in every other firefighting scenario. The industrialized world has shifted toward principles of Physical Security Assessment to minimize the threat. It involves inspecting a facility and determining the danger of intrusion without notice or a suitable reaction (Porter et al. 2014). A security specialist who is highly valuable in their field and whose expertise and experience bear a representative cost is needed to accomplish this historically. Because of this, security issues frequently come as virtually an afterthought in many situations.

2. Methodology

The following criteria have been applied to include and exclude sources from the analysis. Adopting the inclusion criteria from (Akinlolu et al. 2020), the following criteria will be used in the selection of publications. The methodology is presented in Fig 1 below.
i. Only studies published in the last 10 years is included
ii. All articles in peer-reviewed journals were included because their research methodologies and aims could easily be investigated.
iii. Studies in the subject areas of Civil Engineering, Construction Engineering, Facility Management, BIM, GIS, and Social Sciences were considered.
iv. Peer-reviewed publications written in a language other than English were excluded because their impact on the research community cannot be effectively evaluated.

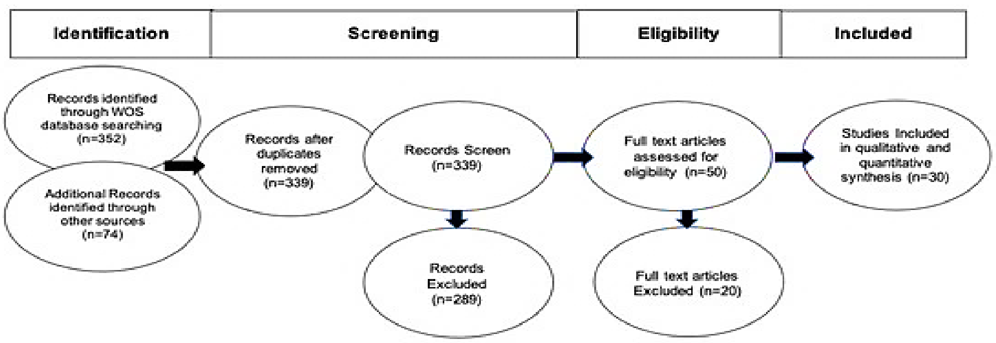

Fig. 1. PRISMA's Systematic Review Process (Adapted from Moher et al. 2015; Salman et al. 2021)

3. Data Analysis

Adopted from (Akinlolu et al. 2020), the following bibliometric techniques are utilized.
i. Frequency analysis to establish publications by country/region distribution, and the number of publications annually.
ii. Co-authorship analysis to present co-occurrence and collaborative network of authors in the selected domain of study.
iii. Co-occurrence of keywords to present the occurrence of correlated keywords CPTED Benefits and CPTED Disadvantages, CPTED Criticism, etc. It facilitates the visualization of secondary literature in the aforementioned areas over time.

3. 1 Bibliometric Analysis

The bibliometric analysis of the frequency of publication was performed using VOSviewer®, and the research topic gained popularity in the academic and research community after the year 2000 (refer to Fig 2). Although the research topic has been around since the 1970s, it did not capture the attention of researchers until 2000. It is easy to argue that the post-2000 era presented the built environment's research and professional community with enormous challenges in keeping building occupants "safe," in addition to other traditional requirements and expectations. With the changing world since the year 2000, an enormous increase in research related to the role of the built environment and safety is hypothesized for further investigation.

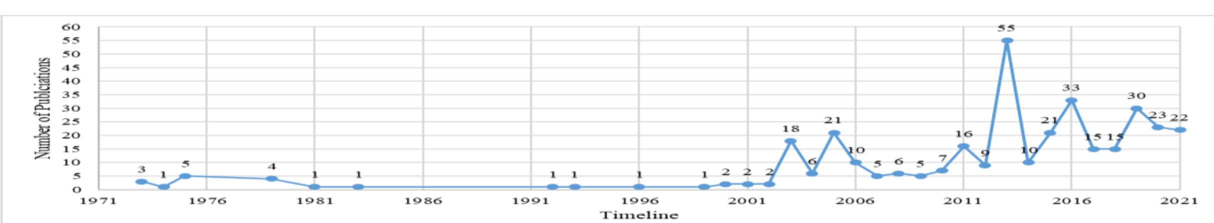

Fig. 2. Frequency of Publication (1973-2021)

The bibliometric analysis of research locations (Fig 3: top left) reveals that the United States has been the focal point of CPTED, followed by Australia and England. Fig 3 shows cross-country collaborations, implying that CPTED is a global phenomenon. It should not be limited to a few countries; rather, there should be a global movement to learn from and adopt mature construction cultures' experiences.

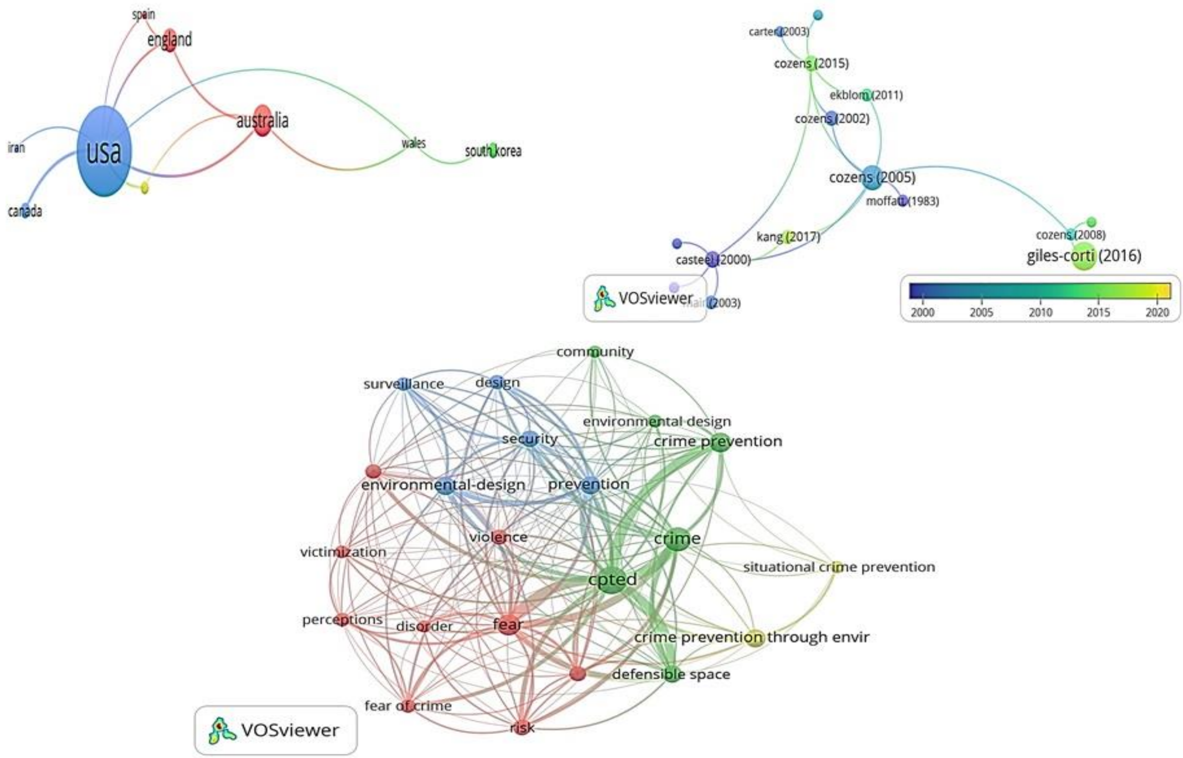

Fig. 3. Bibliometric Analysis

The bibliometric analysis addresses the most prominent citations (Fig 3: top right). A quick glance at the figure reveals Giles-Corti and Cozens' significant contribution to the field of CPTED. Since 2000, when CPTED research gained traction, the respective researcher has been actively present on the research canvas (refer to Fig 2).

For the eminent keywords (Figure 3: bottom center) within the domain of CPTED, it is critical to understand the Occurrences and Link Strengths of the top ten most repeated keywords. According to (Guo et al. 2019), in the VOSviewer manual, the link strength has a positive numerical value, and the larger this number is, the stronger the link. Furthermore, the total link strength represents the sum of all the link strengths of its individual links. Using this interpretation, it is important to emphasize the use of the terms "crime-prevention" (Occurrence: 30 and Total Link Strength: 81) and "crime prevention" (Occurrence: 34 and Total Link Strength: 65). When compared to 'crime prevention' 'crime-prevention' is connected to other keywords in a much stronger (Relatively Higher Total Link Strength) sense than 'crime prevention' (Relatively Lower Total Link Strength). We believe that the distinction between "crime-prevention" and "crime prevention" is purely semantic and that the intent of the defining aspect is the same.

3.2 Perceived and Experiential CPTED Benefits Results

According to Peeters and van der Beken, (2017), place design is effective in reducing crime, and the CPTED framework has a particular advantage in that it can be used to develop tangible measures to improve security. There is some empirical evidence that the CPTED policy has been a successful and viable tool for reducing crime rates in several international contexts. According to Cho and Jung (2018). (Baek et al. 2010; Kim et al. 2011; Kim 2007; Park 2010; Shin and Kim 2012). The secondary literature on the topic contends that there is growing evidence demonstrating the success of CPTED (Cozens et al, 2005; Haywood et al, 2009; Armitage et al. 2011), but there are also criticisms.

On this basis, the discussion that follows expands on the international context of CPTED's success in various countries.

- The United States of America, for example, after a variety of CPTED interventions in Portland, Oregon (Kushmuk and Whittermore 1981), there was a reduction in commercial property burglaries as well as "a "stabilization" of the neighborhood's quality of life, physical appearance, and social cohesion among the business community" (Schneider and Kitchen 2002). CPTED has also been implemented in industrial areas. Access control, reducing escape routes, improved signage, target hardening, improved lighting, CCTV, and nighttime security patrols were all examples used in California (Peiser and Chang 1998). Break-ins, vandalism, and graffiti were drastically reduced (from every weekend to bi-monthly), and the industrial park's occupancy rate increased from 75% to 98.5% in one year. The costs of the security measures, according to the Park's management, were far outweighed by the income generated by increased rents, higher occupancy rates, and shorter vacancy periods (Schneider and Kitchen 2002). In addition to these CPTED-focused studies, evaluations in other fields provide evidence of the approach's effectiveness. A review of over a hundred problem-solving projects conducted by police departments across the country by the US Department of Justice found that 57 percent of successful projects used CPTED strategies as a major response (Scott 2000).
- Canada- Schneider (2002) reviewed "successful" CPTED case studies in Canada (though these were not independently evaluated) and contends that it is most successful "when residents are made aware of and educated on the design strategies that have been implemented and their role in maximizing the potential of these strategies."
- United Kingdom- Piroozfar et al. (2019) observed that ever since the interventions were implemented in 2011, crime rates in Brixton Town Centre BTC, London, UK have decreased, while rates in other parts of England and Wales have increased. It lowers the overall costs of crime prevention when it is considered early in the design process and involves all stakeholders, particularly communities and space-user groups.
- Australia- According to (Wilson and Wileman 2005), the results of their experiments revealed that CPTED principles reduce crime along Australia's Gold Coast. The study team also saw CPTED as a proactive crime prevention method that could be used in residential areas, retail centers, housing estates, and parks. CPTED was cost-effective because it required no significant increases in new resources, but rather better and more judicious use of existing resources. One positive outcome of the study team's empirical work in developing a "Safe City" plan was strong evidence that crime and fear of crime could be reduced if the good design principles outlined in CPTED Theory were applied to existing urban and suburban projects.
- Republic of Korea-Kim et al., (2019) establish that CPTED elements installed in the target area positively reduced crime rates, which is consistent with the findings of a previous study on the first generation CPTED, which found that the CPTED elements reduced burglary crime rates (Jeong et al. 2017). CPTED principles, when correctly applied and enforced, discourage crime, improve quality of life, and reduce fear. For example, in Seoul, South Korea, adequate closed-circuit television, street lighting, and maintenance played a significant role in reducing crime fear (Lee et al. 2016).
- The Republic of Ghana- Gouveia et al. (2021) cite (Owusu et al. 2015) that CPTED principles were applied in Accra and Kumasi, Ghana, by creating ‘security islands' (i.e., higher walls with burglar-proof windows and doors) with low community solidarity in middle- and upper-class neighborhoods (Owusu et al. 2015).

3.3 Crime Prevention through Environmental Design (CPTED) Short Comings

Although first-generation CPTED has proven effective in several cases, it has several drawbacks. First, "irrational" offenders—those under the influence of drugs or alcohol—may be less likely to be deterred by first-generation CPTED strategies. Second, negative socioeconomic and demographic dynamics can reduce the effectiveness of CPTED strategies: on the one hand, social conditions can foster fear, reduce the desire to intervene and result in an individual withdrawing into a heavily fortified home (Merry, 1981). It is to become more focused on reprogramming the urban space through digital means and becoming more sustainable while maintaining the first generation's principle of surveillance and control and the second generation's principle of effective physical design and socio-cultural diversity (United Nations Interregional Crime and Justice Research Institute (UNICRI) and (MIT 2011). According to Peeters and van der Beken (2017), more caution is needed because the relationship of CPTED characteristics to the risk of burglary is different in the city center than it is further away from the center. This implies that burglary prevention advice should be site-specific. As a result, burglary prevention advice should focus on the specific characteristics that are relevant to each house. Arabi et al. (2020) conducted a CPTED study in Iran for a historical project and concluded that the first generation of CPTED, which included only physical issues, was unable to protect and secure the historical project; the second generation did not fully conform to the historical project's social background. Furthermore, the failure of location-based factors has increased crime rates and resident dissatisfaction.

According to Cozens et al. (2018), basic methods are likely to improve the implementation of fundamental CPTED principles, whereas assessment, which includes temporal analysis and experiential user testing, may deliver greater levels of design insight and longitudinal validation opportunities. The need to investigate people's responses to yet-to-be-built environmental settings is a common problem for environmental psychologists, architects, urban designers, planners, and criminologists alike. Although some studies do not support the claim that CPTED is effective, many report that manipulating design factors were less effective than addressing other variables (such as bureaucracy, political will, multi-agency coordination, community engagement, support, and so on) rather than reporting no effectiveness at all (e.g., Judd et al. 2002). In two empirical studies, Taylor (2002) discovered that social, cultural, and economic factors were more important than design in explaining crime reduction (Donnelly and Majka 1996,1998). It is also argued that CPTED is frequently overlooked by built environment practitioners due to competing priorities during the design and planning processes (Colquhoun 2004; Schneider and Kitchen 2007; Paulsen 2012; Knapp 2013; Monchuk 2016). According to Fisher and Piracha (2012), the lack of cohesion among many of the key stakeholders, professionals, actions, and conceptual understanding of CPTED demonstrates the potential value for coordinated training programs that seek to engage the multiple agents involved in the design and maintenance of any given space at the same time.

According to Cozens et al. (2018), there is currently no discussion of how different types of CPTED analysis may be enabled using both BIM and VR technologies. There was no research that used video footage to investigate burglary or other types of crime. The ongoing development of video game engine technologies raises the intriguing prospect of criminal scenario testing of environments. According to (Cozens 2014), CPTED must constantly adapt to changes such as increasing urbanization, population densities, population diversity, new technologies and products, new ways of life, and emerging crime problems to maintain its popularity. It must also remain reflective and strive to evaluate and comprehend its successes and failures. It is no longer sufficient to be aware of generic CPTED solutions. It is necessary to move away from cookbook approaches and instead consider the specific characteristics of each situation (Cozens 2014). Mihinjac and Saville (2019) both seek to improve CPTED as a theory by returning to its foundations in Jacobs (1961), Jeffery (1971) and Newman (1972) to re-inspect and redefine CPTED. By developing a new theory that integrates human motivation and aspirations within a neighborhood Livability Hierarchy, the Third Generation of CPTED will be able to expand both the situational focus of First-generation CPTED and the neighborhood focus of Second-generation CPTED.

3.4 Future Direction: CPTED and Visualization

Visual representations of environments have been used in criminological research for a relatively long time. As new imaging technologies have evolved, they have been used to assess the perceived vulnerability of real or proposed environments to various types of crime, including burglary. Maps and diagrams; Physical models; Photographs; Video; Panoramic photography, Street View, interactive imagery; Game engines; and experiential testing are all supported by the literature.

Table 1. CPTED and Visualization

Visualization Technique	Citation	Purpose
Maps and diagrams	(Cozens et al. 2018); (Andresen 2014); (Kim and Shin 2014)	The mapping of crime "hot spots" enables more coordinated efforts for crime prevention and policing responses. Early theories were concerned with both where criminals lived and where crimes were committed. Environmental criminology research, crime map implementation, and GIS technologies are becoming mainstream.
Physical models	(Fisher 2005)	Building scale models could be used in crime scene investigations.
Photographs	(Bennett and Wright 1984); (Cozens et al. 2001, 2002b); (Nee and Taylor 2000); (Shaw and Gifford 1994); (Wright and Logie 1988).	Photographs have been used to stimulate perceptions of crime (including burglary) in a variety of housing studies.
Video	(Heft and Nasar 2000); (Huang 2004); (Orland 1993)	There have been few validity studies on the use of video simulation, but those that have been conducted generally suggest that video has better validity than static photographs.

Panoramic photography, Street View, and interactive imagery	(Cozens et al. 2002b, 2003, 2004); (Whitaker et al. 2004); (Park et al. 2008, 2010, 2011); (Toet and van Schaik 2012); (Tutt and Harty 2013); (Piroozfa et.al. 2019); (Shaw & McKay 1942); (Cozens et. al. 2018)	BIM offers an exciting opportunity to better integrate CPTED principles in residential buildings while also providing insights into the dynamic relationship between the built form and crime.
Game engines and experiential testing	(Cozens et al. 2018); (Wang et al. 2014); (Klepto Meerkat Gaming 2016); (Bereitschaft 2016).	Based on experimental testing, more complex video game simulations of how burglaries and fires might be managed are likely to yield more sophisticated crime management strategies. To that end, video games that specifically simulate committing residential burglaries are being developed.

4. Conclusions and Recommendations

The paper presents a review of the literature based on the PRISMA protocol. The purpose of this paper was to present the benefits and drawbacks of Crime Prevention through Environmental Design (CPTED), as well as to identify future research directions. The number of publications in this field has increased since the year 2000. It is easy to argue that the post-2000 era presented enormous challenges to the built environment's research and professional community in keeping building occupants "safe," in addition to other traditional requirements and expectations; with the United States serving as the primary focus of the research. It has been discovered that there is a lack of consistency in the use of CPTED vocabulary. The knowledge is currently progressing toward a more holistic third generation of CPTED; the groundwork had been laid by two previous generations who based their work on target hardening, defensible space principles, and social cohesion and companion guardianship principles. It should not be limited to a few countries; rather, there should be a global movement to learn from and adopt mature construction cultures' experiences. With the rising crime rate, a multifaceted approach is needed to combat the threat of crimes against the built environment. CPTED has been proven successful in most parts of the world, despite its limitations and challenges. The existing secondary literature documents the success stories as well as the associated challenges. Access control, reducing escape routes, improved signage, target hardening, improved lighting, CCTV, and nighttime security patrols has been found to be effective to reduce crime from the built environment's point of view. The introduction of the latest visualization techniques such as gamification, VR/AR, and BIM, as well as developments such as Digital Twin, etc; can be used to increase the efficacy of CPTED, with preliminary studies being conducted.

The limitations of the current study along with recommendations for future study are elaborated in the succeeding discussion. The limitations of the study are presented for i. Research Design: and ii. Analysis and Discussion. They are elaborated as follows:

- Research Design- The secondary literature for this study was obtained from Engineering Village and Web of Science (WoS). As a result, one of the limitations is the inclusion of a diverse range of databases. Although it can be argued that many manuscripts will be shared by the databases, it is still worthwhile to include several databases. Scopus, Google Scholar, The Lens, Journal Storage JSTOR), Science Direct, ASCE Library, the American Society of Civil Engineers, and other research databases can be added. Grant and Booth (2009) can provide more detailed guidance for the design of Literature Review Papers. They compared and analyzed over ten different review types and associated methodologies. Based on their findings, an appropriate strategy that is comprehensive and specifically suits the broad Civil Engineering domain with a focus on Building Construction, Building Science, Construction Management, and so on can be devised.
- Discussion and Analysis- The discussion and analysis focused on CPTED studies conducted for the commercial built environment. However, ample literature is also available for public places such as parks, bus/train stations, and so on. The current study employed Bibliometric Analysis; as future work, the analysis can be carried out in the manner described by Zhong et al. (2019), in which the authors conducted a scientometric analysis of a construction-related topic of interest (as an example). Data obtained from a diverse database should be subjected to Bibliometrics, Scientometrics, Webometrics / Cybermetrics, Informetrics, and Altmetrics analysis, according to Chellappandi and Vijayakumar (2018).

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A bibliometric review of Opportunities in BIM-Industry 4.0 Integration in the Architecture, Engineering, Constructions and Management (AECOM) Sector

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Abstract
The built environment (BE) sector in Nigeria is continually overwhelmed with inefficient construction processes, and delayed project delivery, among others. Developed economies are fast adopting and implementing BIM-Industry 4.0 technology which has helped improve their productivity and boosted their national economies. However, the built environment (BE) Industry in Nigeria has made slow progress in this regard. Therefore, this study aims to identify possible avenues for the integration of BIM technology in construction projects in the BE sector for process efficiencies and increased productivity. This study likewise identified the challenges to BIM technology integration in the sector and proposes strategies for its nitration, adoption and implementation for enhanced project outcomes, improved efficiency, and national development. To ensure the credibility of this study, the research is based on a bibliometric review of two hundred and seventy-one journal articles and conference publications on BIM adoption and implementation in the architecture, engineering, construction, operations and management (AECOM) sector identified from the search of the SCOPUS database. Keyword 'BIM Adoption' OR 'BIM Implementation' were used for the search and the extraction of the articles. The extracted bibliometric data were analysed using the VOSviewer software. This study explained that owing to the identified successes and benefits that BIM offers, many developed nations have either fully adopted BIM technology or are in the advanced stage of its adoption. However, the Middle East and Africa are either in the early adoption stage or have not yet adopted BIM. Therefore, there is an urgent need for BIM to be widely adopted and implemented in the Nigerian built environment industry for improved project deliveries and productivity.

Keywords
Building Information Modelling adoption, digitalization, Industry 4.0, construction industry.

1. Introduction

Over the past few decades, there has been a considerable institutional and organizational transformation in the AECOM industry. According to Ibem et al. (2011), the complexity and pace of the construction process are always evolving, and there is a growing need for enhanced productivity in line with changes in consumer needs, technological innovations, market shifts and economic globalization. According to Shuhaimi et al. (2022), there have been four major industrial revolutions that have influenced human lifestyles. The author further noted that many industrial sectors are currently experiencing the fourth industrial revolution (4IR), which makes BIM skills necessary for AECOM professionals. Jin et al. (2018) stressed that numerous 4IR technologies have been employed to minimize the difficulties experienced in the sector and to increase productivity and competitiveness. Sharag-Eldin & Nawari (2010) put forward that BIM is changing the way structures and buildings are designed, constructed, assembled, commissioned, operated, and managed in combination with other new digital tools that the building industry has adopted. Furthermore, Sepasgozar et al., (2023) opined that because of the effects of BIM integration on organizations, technology, processes, and the body of knowledge, it is regarded as one of the eleven revolutionary and disruptive new advancement in the global AECOM business.

According to Sepasgozar. (2023), BIM is a creative, cooperative process supported by digital technologies for information distribution and management which with digital twin (DT) is able to converge the 4IR tools. Additionally, it encompasses a broad variety of ideas, methods, and techniques used to generate and maintain all project-related data throughout the project lifetime (Succar et al., 2012; Ahn and Kim, 2016). Similarly, (Elmualim & Gilder, 2014) opined that rapid improvements in designers' capacity to convert design information into inferential knowledge may help practitioners in the AECOM industry to develop and assess more alternatives with reasonable accuracy and sooner in the design process for heightened project efficiencies. Furthermore, BIM allows for digitization of the entire phases of a building's lifecycle and is invaluable for facility management, multi-discipline design decision-making, production of construction drawings, and costs management (Elmualim & Gilder, 2014). This study is necessitated by the realization that BIM is the most revolutionary and transformative 4IR technology in the industry which could be employed to proffer solutions to the inefficiencies in the Nigerian AECOM industry which has resulted in delayed project deliveries, wastes and poor productivities in the sector. This study therefore aims at identifying the challenges to BIM integration in the sector and proposes strategies for its nitration, adoption and implementation for enhanced project outcomes, improved efficiencies, and national development. This study involves a review of global BIM adoption in AECOM industry and an analysis of the avenues for the integration of BIM technologies in the AECOM sector. This study aligns with earlier researchers' opinion that there is an urgent need for industry-wide BIM uptake in the AECOM industry. In putting forward the global BIM adoptions with the level of successes registered, the avenues for BIM integration in the AECOM industry and recommendations, this study will achieve the goal of sparking more research interest in this area for more BIM awareness campaign and subsequent adoption in AECOM businesses in Nigeria and in developing countries generally.

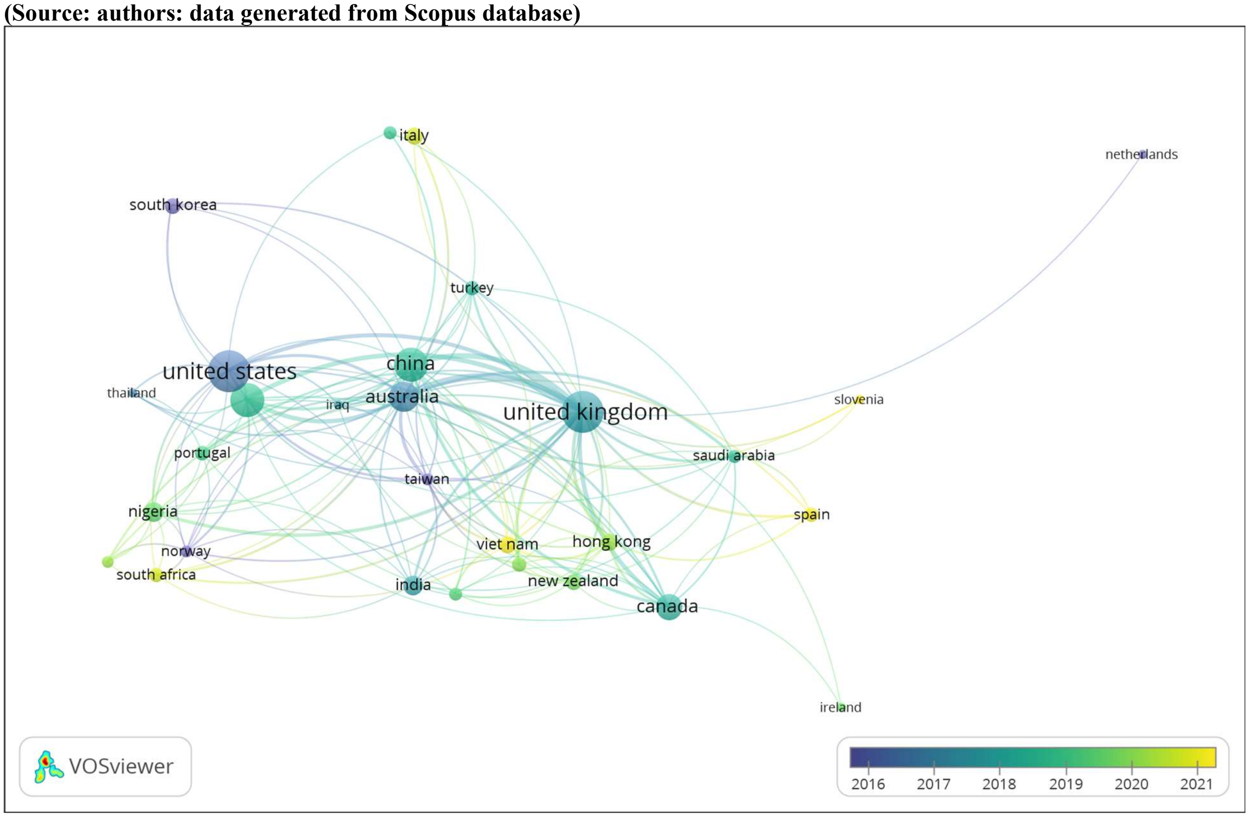
2.0 Research Methodology

This study was conducted by reviewing existing literature on global BIM adoption and implementations in the AECOM industry using a bibliometric literature review method from the SCOPUS database. The selection of this database was as result of its broad-base and its wide recognition and utilization for scientific research works as it covers numerous scientific studies (Guz, 2009), and is considered the broadest scientific database. The bibliometric review was carried out to determine the BIM adoption publishing trends and the countries with the highest focus on BIM adoption and implementation while realizing relevant literature in the subject area for the study. The search on the SCOPUS database was conducted using the keywords 'BIM adoption' OR 'BIM Implementation', following which 1089 publications were realized. Exclusion and inclusion criteria were then applied to limit the search to relevant articles in the study area. The search was limited to English only, open access journal articles and conference papers, published between 2006-2022 in the Engineering, Environmental science, and Computer science subject areas only. Following this, 318 publications were realized. The document was exported to VOSviewer software in CSV Excel format for analysis. The analysis was based on the number of citations and countries, with countries having a minimum of 2 articles and 10 citations as the threshold. Out of the 60 countries initially represented, 29 met the exclusion and inclusion criteria. A total number of 271 articles and 29 countries were then realized as shown in Table 1.0. The map showing BIM adoption or implementation articles by country was generated by the authors on VOSviewer, for visualization as shown in Figure 1. Furthermore, the 271 conference and journal articles realized were scrutinized to find the most relevant articles that could be employed for the literature review. A total of 31 articles were eventually selected based on their significance for this study as they discussed BIM adoption and integration in the AECOM industry. Other relevant documents realized from searches on google scholar and the SCOPUS database using 'digitalization', 'Industry 4.0', 'construction industry' keywords were also adopted for this study.

3.0 Global BIM technology adoption in the AECOM sector

BIM use in the architecture industry has increased recently around the world. A map showing the trend of BIM adoption and implementation publication generated from the VOSviewer software to support the existing literature in the subject area is shown in Fig. 1.0. According to (Ahn & Kim, 2016), the United States played a leading role in the acceptance and adoption of BIM with the authorization of BIM for public procurement contracts in 2007. The author further noted that the introduction of BIM gradually in Korea was confirmed as a government scheme with the enforcement of BIM on all public procurement contracts beginning in 2016. Several self-directed targets have been set by countries including the UK, Canada, Australia, China, and Norway for the adoption of BIM in the procurements of significant public sector projects according to Alwan et al., (2014). BIM in Malaysia seems to be at the pre-BIM stage, in which the emphasis is on raising industry stakeholder awareness (Rosli et al., 2016). According to Kepczynska-Walczak (2018), the UK and Denmark are unquestionably the two European pioneers in BIM adoption. In France, BIM struggles to be integrated in the AECOM industry (Hochscheid & Halin 2018). According to Wallin & Both (2017) in Germany, BIM adoption is at a very early stage. Poland have joined the EU BIM Task Group and is at the beginning stage of BIM adoption as reported by Kepczynska-Walczak, (2018). According to Akdag and Maqsood (2020), the Middle East and Africa's uptake of BIM is still regarded as being at the beginning stage. Furthermore, the author opined that to generalize sustainable practices such as BIM adoption, it is crucial to examine emerging situations and comprehend their opportunities and implementation challenges. BIM adoption is still very important to the Nigerian AECOM businesses (Kepczynska-Walczak, 2018).

Figure 1.0 : Global researches on BIM Adoption Map on VOSviewer
(Source: authors: data generated from Scopus database)



The map on BIM adoption and implementation publishing trend by countries, publications and citations in Fig. 1.0 corresponds to the existing literature as it indicates that United Kingdom, Australia, United States are leading in BIM adoption and implementation and in publications in this subject area, since 2016, while Canada and China followed in 2018 and 2019, respectively. Nigeria gradually joined the BIM adoption and implementation discussions from 2019-2020, the country is still at the beginning stage of BIM adoption. The results from this analysis projects the need for BIM adoption and implementation in the developing world, particularly in the Nigerian built environment industry.

Table 1.0 – BIM adoption and implementation publications (Source: authors using VOSviewer)

Number	Country	Documents	Citations	Total link strength
1	United Kingdom	38	1927	163
2	Australia	20	908	111
3	United states	38	649	42
4	Canada	16	612	42
5	China	26	333	62
6	Taiwan	3	263	34

7	Malaysia	26	189	52
8	Hong Kong	7	174	32
9	Saudi Arabia	4	169	23
10	Nigeria	9	145	21

Other countries captured in the analysis includes South Korea, Norway and India with (6, 3, 9 publications and 122, 114 and 86 citations respectively). Pakistan, Iraq, and Portugal with (4, 2, 5 publications and 84, 77 and 77 citations respectively). Germany, Israel and Italy with (5, 4 and 7 publications and 95, 63 and 36 citations respectively). New Zealand, Netherlands, Turkey with (6, 2 and 5 publications and 35, 31 and 31 citations respectively). Slovenia, Thailand, Ireland with (2, 2, 2 publications and 29, 29, 27 citations respectively). Ghana with 3 publications and 22 citations and Vietnam, South African and Spain with (7, 5, 5 publications and 18, 14, 12 citations respectively). The following avenues for integration of BIM in the AECOM industry were deduced from the global adoptions literature.

3.1 Avenues for integrating BIM technology in the AECOM Industry

According to Alaloul et al., (2016), the five main components of BIM are visualizations, teamwork, modeling, optimization, and the ability to plot. The primary benefit of BIM is the earlier development of digital model and simulation of the projects from the initial project operations to its realization, as a result, BIM reduces planning errors, supplies quick calculations, anticipates additional costs, and displays replacements (Khosrowshahi & Arayici, 2012; Alaloul et al., 2016). BIM will speed up building development by attempting to establish a shared repository for electronic data pertaining to a project or property (Ahn & Kim, 2016). The author further noted that to introduce and use BIM effectively, a considerable adjustment must be made to the traditional construction process. Thus, BIM education is indeed essential for both practitioners and students. Azhar (2011) asserts that by processing the final accurate data throughout all stages of a project's lifecycle, beginning from design development through execution and conservation, advanced BIM utilisation would boost project schedule, budget, productivity and drastically reduce errors. According to Alaloul et al. (2018), BIM technology is utilized to get ready for the industrialization of the construction sector. The author further opined that, to aid in decision-making about the choice and use of finished parts, BIM produces a 6D model from the three-dimensional visualisation parameters and adds time, cost, quality delivery and sustainability aspects to it. Additionally, the integrative and compatible usage of BIM and digital data processing, benefits the precise formulation, intelligent management, and information distribution and the development of practical standards (Alaloul et al., 2016; Wang et al. 2018). Therefore, BIM can significantly enhance the construction industry's ability to operate with its numerous digital tools and methodologies.

The term BIM, referring to all operations made possible by the power of digital, computer-readable building data, has numerous benefits for the AECOM sector (Eastman et al., 2011). These benefits include making a multitude of building data available for visualisation, performance assessment, simulations, communications, and output generation (Azhar 2011). Furthermore, Azhar (2011) stressed that by enabling automatic collision detection analysis through BIM, which entails displaying each crucial clash, exchanging information to seek resolutions, and modifying a model in a single platform, BIM also streamlines construction workflow and increases projects profitability. Casasayas et al. (2021) stated that professionals with BIM skills and expertise are in high need in the AECO market owing to its well-recognized opportunity for the industry. BIM360, an Autodesk cloud service connects the many phases of a development project's lifespan, connects project team members, and allows for collaborations and communications with other groups (Tayeh and Issa, 2021). The author further highlighted that BIM360 optimizes the project delivery processes by providing the resources necessary to prompt informed decision-making because the platform emphasizes the importance of extremely well-managed data which is consistently maintained and up to date. Additionally, BIM cloud technology will provide full access to facility management (FM) analytics to any interested parties (Alaloul et al. 2018). Due to the digitalization of construction brought forth by the 4IR, BIM has been the industry project's focus (Maskuriy et al. 2019). BIM is regarded as the ideal setting for collaborations and the development of robust and cutting-edge solutions for the AECOM industry by providing additional layers of information that may interface in real time (Bilal et al. 2015). The development of BIM presents fresh approaches to predict, manage, and regulate the quality and amount of material to enhance material flow (Alaloul et al. 2018). The key components of the 4IR, which includes: cyber-physical systems (CPS), the Internet of things (IoT), the Internet of Services (IoS), artificial intelligence (AI), smart production applications and big data, can improve the use of BIM all through the construction stage according to Hermann et al. (2016), by improving waste management practices, monitoring of project activities, and supervising the personnel, while raising output.

According to Jiang et al., (2018), by moving the construction processes away from construction sites and into a controlled factory setting, off-site constructions using BIM offers an alternate strategy. Furthermore, to increase the efficiency of the construction industry, BIM needs to be employed in the project delivery of off-site constructions (Abanda et al., 2017; Jin et al., 2019). Owing to its collaborative capabilities, BIM could be employed in managing the dispersed construction operations more effectively. The use of BIM as a digital channel to increase the effectiveness of project deliveries calls for both technological advancement (such as improved interoperability across various software platforms) and the Integrated project delivery (IPD) strategy. BIM is being combined with other digital technologies, such as the IoT, geographic information systems (GIS), and virtual reality (VR) for smooth project management and control, Jin et al., (2019) opined. According to Akdag and Maqsood (2020), BIM can expand its functionality to more varied dimensions owing to technology advancements including levels of detail, lean constructions, industrialized constructions, disaster management systems, emergency management, as well as smart buildings and remote controls. Abideen et al., (2022) noted that buildings' operations and maintenance (O&M) life cycles consists of about 60% of the overall life cycle expenses of assets. As the O&M stage normally lasts the longest in a building's lifecycle, whereas the design and construction stages together often lasts two to five years, BIM is essential for realizing a solid return on investment (ROI) for 20 years or longer (Kensek, 2015; Chan et al., 2016). This shows that the capital expenditure for construction is outweighed by the ongoing expenditures of a property's operations and maintenance and suggests that it is possible to achieve significant cost and time savings in O&M using BIM (Akcamete et al 2019; Abideen et al., 2022). Certainly, enhancing data visualizations and monitoring can help with failure identification and reporting in O&M, Kassem et al., (2015), added. BIM has applications in a variety of FM-related fields, including the control of energy usage, facility security, and the monitoring of repairs and maintenance operations (Becerik-Gerber et al., 2012). According to Asare et al., (2020), the design, construction, operations, management, disposal, or replacement of buildings and infrastructure are all being impacted by BIM in the AECOM sector. BIM, therefore, holds enormous promises for more efficient project processes, effective projects deliveries and heightened successes generally, for AECOM businesses. The level of successes recorded from BIM implementations study are elaborated to promote BIM integration in the Nigerian AECOM industry.

3.2 Level of successes in BIM technology integration

According to Akdag and Maqsood (2020), BIM implementation enhances the design processes and produces more sophisticated design solutions by enabling a more thorough investigation of constructability and sustainability than is often done. The author further opined that with BIM, architects are capable of increased deliveries. Therefore, AECOM businesses must invest further in hardware, software and in advancement of BIM experts if it wants to be the leaders in the market in the digitalized era (Throssell, 2012). According to Saxon (2013), large architecture companies are more likely to have used BIM than are small and medium-sized businesses. These firms invested time and resources to make the transition from conventional methods to the BIM process, while they claimed that only three BIM projects were necessary to see the benefits of BIM adoption. BIM adoption has resulted in increased profitability for the big firms that have adopted and implemented it in the USA AECOM industries, the author further opined. According to Sebastian et al. (2009), a successful strategy among clients and project stakeholders should be employed to implement BIM, the setting up of internal BIM object libraries for each firm that adopts BIM reduces ICT protocols and time. Masood et al., (2014) reported that BIM is a quicker and more efficient way for design and construction management. The top three BIM benefits were determined to be design quality improvement, raised construction quality, and decreased reworks (Akdag and Maqsood, 2020). Architects and AECOM organizations that utilize BIM were reported to be knowledgeable of its 4D, 5D, and 6D facilities for time, cost and facility management respectively as BIM is not only a tool for visualization, it is also crucial for pricing, scheduling, clash detections, and coordinating data, owing to its parametric and collaborative attributes. The widely acclaimed BIM implementation success levels have led to increasing discussions on the subject, and global adoptions in the industry by the day as shown in Fig. 1.0. However, there are notable barriers to its adoption and integration.

3.3 Barriers to BIM technology integration

According to Babatunde et al., (2020), there are often certain adoption obstacles for modern technologies. Many BIM adoption hurdles for project management are caused by a lack of technological understanding and the challenges of changing the development and design procedures in businesses (Ahn & Kim, 2016). It is essential for the AECOM industry to have individuals with relevant technical competences and BIM capabilities in order to further the growth of BIM (Rosli et al., 2016). According to Muller et al., (2016), the absence of interoperability, primarily related to data and formats, which makes using BIM challenging, is a further issue that the AECOM industry must deal with as the benefits of BIM uptake may be contested because of this. Since BIM projects require more staff to be allocated in the initial design stages of the project, contrasting to 2D CAD, which tends to assign more professionals in the details stages, the modifications to the workflow also present certain issues (Ibrahim et al., 2012). According to Akdag &

Maqsood, (2020), the most obvious difficulties with BIM implementation in the AECOM industry have been identified as the increase in cost. Businesses are reluctant to spend in BIM setup because it is difficult to determine the expenditure and the return on investment (ROI), according to a report for Autodesk (Erin, 2016). Ahn & Kim (2016) stated that to introduce and use BIM effectively, there is need for a considerable adjustment to the traditional construction processes.

4. Lessons learned

Reviewed literature revealed that BIM adoption particularly in developed nations has brought about improved project efficiencies in the design and implementations stages alike. Evidence from previous studies also confirms that AECO firms that adopted BIM in their projects reported that although more time is devoted to the project in the design stage, in collaborations amongst project stakeholders, clash detections and rectification of errors, the construction processes was coordinated with minimal change orders and reworks therefore resulting in cost savings and in the completion of the projects on schedule as opposed to non-BIM projects. BIM use also results in reduced material waste and improved quality of works and project outcomes with the increased availability of all construction details and specifications. Moreover, BIM projects involve professionalism and skilled labor in the office and on site thereby promoting high quality construction and efficient project deliveries. It is deduced from literature that BIM integration in the AECOM sector generally results in enhanced design and construction productivity and national development.

5. Conclusions and Recommendations

For increased BIM diffusion, Succar & Kassem (2015) suggested nine crucial actions in addition to the actors. They include making people aware of the technology, encouraging its use, observing its adoption and implementation, educating and training professionals on BIM use, motivating practitioners, tracking the adoption and implementation, prescribing, enforcing BIM use, and regulating the use of BIM in the industry. Universities may have a significant impact on these initiatives. To support the shifts in the AECOM sector towards greater project efficiency with the help of digital technologies and connected multiple stakeholder platform, the government authorities, academia, and industry experts should establish a common and consistent view on the movements, needs, constraints, and actions (Jin et al., 2019).

As evidenced in the global adoption literature, government played a big role in enabling BIM adoption and implementations in the developed world. Government policies and support for the built environment industry go a long way in promoting BIM uptake for projects. The role of government in supporting, strategizing, and enacting policies for BIM adoption and implementation in the AECOM sector to meet the challenges of the industry cannot be over-emphasized. There is need for the Nigerian government to enact policies mandating the use of BIM for all significant public projects costing over 500 million naira, for example. BIM education of AECOM practitioners is key to realizing the BIM adoption and implementation goal. This study recommends advanced level BIM integration in the curricula of all AECOM disciplines in higher education institutions (HEIs) in Nigeria. Also, for practitioner already engaged in the industry to be BIM-knowledgeable, it is suggested that BIM certification from approved training centers be made a pre-requisite for professional licensing in this sector. Furthermore, as BIM is advancing and other 4IR technologies are being adopted globally in the industry, advanced BIM certification and/or demonstration of proficiency in the utilization of other emerging 4IR technologies should be adopted as a continuous professional development (CPD) programme undertaken prior to annual practice license renewal, for the architectural profession. The Architects Registration Council of Nigeria (ARCON) and the Nigerian Institute of Architects (NIA) are called upon to take this into consideration as architects are expected to be at the fore-front of the national BIM adoption, being the initiators and coordinators of the design process. This should also be applied to other AECOM disciplines in the sector. There is also a need for academia and industry to collaborate in research on the emerging 4IR technologies and promote awareness and enlightenment in this regard.

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Appraising the Prevalence of Task Demands among the Construction Workforce in South Africa

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Abstract

This study investigates occupational stress among the South African construction workforce. The study focused on the task demands/stressors directly linked to the job a worker is performing. Task demands in relation to the type of occupation, job security, workload, and lack of innovation can result in low morale among the workforce. A combination of these factors results in job stress which affects employee's mental health and subsequently their overall well-being. In this quantitative cross-sectional study, survey questionnaires were distributed among a convenient sample of contractors in South Africa. The study achieved 201 valid responses and the internal reliability was 0.777 and deemed acceptable. Convenience sampling was favoured due to the proximity of the respondents to the researcher and also, to speed up the data collection process due to the timeline of the study. Data were analysed using descriptive statistics methods in IBM SPSS v28. The findings of the study revealed that contrary to expectation, most workplaces promoted equality and had internal policies to prevent bullying, discrimination of race; sex and xenophobia, which are unique in South African. Further, workers received support from their organisations in relation to tasks, and adequate tools and equipment for tasks. However, workers identified some challenges relating to multi-tasking, strict work environment and job insecurity. Although these responses had received high agreement levels, they were not fully satisfactory indicting that they are still a problem to some degree. This study achieved the desired homogeneity in relation to the representation of worker groups. This study is important in appraising task stressors in the South African construction industry and how they compare to those in developed countries. Also, in determining similarities and differences, stakeholders will focus on specific aspects unique to South Africa.

Keywords

Task Demands, Occupational Stress, Mental Health, Construction Workforce, Construction Industry

1. Introduction

The construction industry is plagued with fatalities that emanate from several known and unknown factors. Early research focused on safety and little attention was given to health, more so, mental health. Mental health may be defined as the state of well-being whereby an individual can manage the normal stress of life based on their perception, working fruitfully and productively and also being able to make contributions to society (WHO, 2001). Mental-ill health, an antonym of mental health, is defined as an individual's inability to realise their potential and to work productively to make contributions to their society (Herrman and Jané-Llopis, 2012). Psychological stress is often a precursor to mental ill-health. Stress emanates from non-specific demands/stressors placed on the body (Selye 1976), and in the context of workplaces, these demands relate to an individual's inability to satisfy the work demands or tasks (Topper, 2007; Vermunt and Steensma, 2005; Varca, 1999; Randall and Ross, 1994; Beehr, 1995).

Occupational stress is a dangerous illness for industrialised economies and threatening production as it affects the both the physical and the mental health of the workers (ILO, 2014). Occupational stress has become a critical public health concern in recent years with detrimental effects on human health (WHO, 2019; Kawakami et al., 2004). Psychosocial risks and occupational stress are increasingly becoming some of the most challenging issues in occupational health and safety (EU-OSHA, 2021) with reports indicating that about half of the European workforce consider stress to be common at their workplaces, contributing to about half of all lost workdays. Further, stress was reported to be the second most prevalent work-related health problem and it is believed that the number of workers suffering from occupational stress-related illnesses is likely to increase (ILO, 2014). As with many other mental health-related issues, stress is often stigmatised or misunderstood (EU- OSHA, 2021). However, occupational stress can be manageable and treated like any other occupational health and safety risk when addressed at an organisational level rather than addressing it as an individual burden (ibid). The prevalence of occupational stress is now widely accepted and is known to have a high cost in terms of workers' health, absenteeism, and low job performance (ibid).

Although the construction industry is regarded as one of the most stressful occupations, the focus on mental health issues such as stress, depression, anxiety and suicide have not received enough attention (Leung et al., 2005; Ng et al., 2005; Liang et al., 2021). Therefore, it essential to monitor and to address the issues of mental health among the construction workforce in order to better understand their effects and to subsequently prevent occupational injuries and increase productivity (Boschman et al. 2013). A considerable amount of literature has been published on the causes of occupational stress among the construction workforce and the issues have remained somewhat similar throughout the studies (Molen, 2000; Boschaman et al., 2013; Bowen et al., 2018; CIOB, 2006; Leung et al., 2016; Sheratte, 2018; Jepson, 2017; Langdon and Sawang, 2018; Bryson and Duncan, 2018; Tijani et al., 2020). Researchers have shown that the adverse working conditions in construction can contribute to stress. The workforce in construction experiences long hours working under pressure with tight deadlines, high levels of conflicts, low job control, lack of managerial support, job insecurity, and lack of work-life balance (Bowen et al., 2018; Langdon and Sawang, 2018; Panahi et al., 2017; Love et al., 2010; Cattell et al. 2016, Sherratt 2018).

The aim of this study is to examine the prevalence of task demands which lead to psychological stress among the South African workforce. Most studies on occupational stress in the construction industry have been conducted in developed countries especially in the UK, USA, Australia and New Zealand with little focus on African countries (Bowen et al., 2013). Developing countries are characterized by extreme socio-economic issues, such as inequality and crime (Bowen et al., 2013). It has also been reported that in South Africa specifically, the nature of mental health issues requires a uniquely South African solution (SACAP, 2019). Furthermore, there exists both a population and a knowledge gap within the South African context on the causal effects of occupational stress among the general workforce and not only on construction professionals as with other previous studies.

2. Methods

From literature, task demands refer directly to the job a worker is performing and includes the type of activity, job security, workload, and use of new equipment and tools (Tijani et al., 2020; Chan et al., 2021). An extensive literature review on the topic was done and questionnaires were formulated from the literature. A snap survey was also conducted (Raliile et al., 2022) and the findings informed how the current study should be structured in terms of which task demands to include especially those formulated by the researcher. A total of 23 task demands were identified as suitable for inclusion and to ensure face validity and content validity, measures were adapted from existing stress and mental health instruments whose validity was reported. Where certain measures did not exist, new measures were developed and the conceptualisation and operationalisation of these new measures was based on theory and literature to ensure both face and content validity. Structured questionnaires were distributed to contractors in South Africa to explore the constructs underlying the research topic. The sample was selected using convenience sampling, and the respondents were South African contractors sampled based on proximity and familiarity to the researcher. This form of sampling maximised the response rate as the study was conducted over a limited period. Some respondents were referrals recommended by other participants – a variant of snowballing sampling technique. Self- administered questionnaires with a series of close-ended questions were emailed. A total of 201 valid questionnaires were received from the respondents after rejected after screening data for missing values, disengaged responses, outliers and extreme values. The study employs a quantitative research approach and data were analysed using IBS SPSS v28.

3. Results

This section presents the analysis of the data collected and discusses the findings. Data were analysed using IBM Statistical Package for Social Sciences (SPSS) version 28. Descriptive statistics was used for data analysis and further interpreted using inferential statistics. Tables were used to present data and key findings.

3. 1 Profile of the respondents

The participants in the study were the general construction workforce working for contractors. The respondents were artisans, construction professionals and construction labourers. Table 1 outlines the demographics/profile of the respondents:

Table 1 Respondents Profile

	Frequency	Percent
Gender		
Male	164	81.6
Female	37	18.4
Total	201	100.0
Age		
18 to 24	16	8.0
25 to 34	87	43.3
35 to 44	65	32.3
45 to 54	24	11.9
55 to 64	9	4.5
Total	201	100.0
Education Level		
Primary/Elementary School	24	11.9
Secondary/High School	119	59.2
Technical/Vocational Qualification	19	9.5
University Degree	35	17.4
No formal schooling	4	2.0
Architect	4	2.0
Construction Manager	7	3.5
Health and Safety Manager/Officer	10	5.0
Project Manager	5	2.5
Quantity Surveyor	11	5.5
Civil Engineer	6	3.0
Forman/Supervisor	15	7.5
Artisan	15	7.5
Construction Worker/Labourer	124	61.7
Other (site clerk and storage managers)	4	2.0
Architect	4	2.0
Total	201	100.0

From Table 1, there were more male respondents (81.6%) than female respondents (18.4%) in the sample. This finding differs from the general gender distribution of the construction workforce in South Africa which usually has approximately 12% female workers (MBAWC, 2018). Most respondents were between the ages of 25 to 34 years (43.3%). And the second most prevalent age group was between 35 to 44 years (32.3%) of age followed by 45 to 54 years (11.9%), 18 to 24 years (8.0%) and lastly 55 to 64 years (4.5%). The construction workforce consists of older workers relative to other sectors as a result of the ageing workforce and lack of interest from the youth to seek employment in the sector. The average age of construction workers is 42.5 (BLS, 2019). However, from Table 1, most respondents were between the ages 25 and 34 years. This can be attributed to recent changes because of Covid-19 as employment trends resulted in the youth experiencing the highest employment between February 2020 and March 2021 (32.5% to 35%), while older workers experienced a decrease from 45% to 41%. Therefore, the findings represent the current employment-to-population ratios in the industry. The responses were obtained from site personnel working for contractors, and are representative of the construction workforce. Construction workers (labourers) and artisans make up about 55% to 70% of its workforce, while construction professional between 30% to 45%. When categorising the working groups into CPPs, and artisans/labourers, the percentage distribution is 29%:71%. Therefore, the sample represents the population of interest adequately.

3.2 Reliability

Cronbach's Alpha reliability test was conducted in IBM SPSS v28 to determine the reliability and internal consistency of the scales that had been used to examine task demand stressors among the workforce. The reliability was deemed acceptabled, as indicated in Table 2. The Cronbach's Alpha coefficients between $0.70 \leq \alpha \geq 0.80$ are 'acceptable' while between $0.80 \leq \alpha \geq 0.90$ are considered 'good' and coefficients $0.9 \leq \alpha$ are 'excellent' (Tavakol and Dennick, 2011). Therefore, the internal consistency of the various scales was deemed acceptable for further interpretation.

Table 2 Reliability Test

Cronbach's Alpha	N of Items
0,770	23

The findings from Table 3 revealed that 57.2% of the respondents work between 0-45 hours a week while 36.8% work between 46-55 hours per week and the rest work for 56+ hours. According to the Basic Conditions of Employment Act in South Africa, workers are permitted to work for 45 hours per week under normal circumstances. The majority of the respondents had indicated working hours between 0-45 (57.2%). However, 36.8% revealed working overtime. Maximum allowable hours per week is 10 hours a week. Therefore, based on the findings, 6% of the workers had worked beyond the legal allowable times. The findings suggest working overtime which is in line with several literature findings (Tijani et al., 2020).

Table 3 Number of working hours

	Frequency	Percent
Between 0 -45 hrs	115	57.2
Between 46-55 hrs	74	36.8
56+ hrs	12	6.0
Total	201	100.0

Table 4 indicates a cross tabulation of the number of working hours in relation to the worker's position. From the findings, construction labourers (61.7%), artisans (7.5%) and supervisors (7.5%) worked most hours than any other personal on site.

Table 4 Number of working hours and Job Title Cross tabulation

		Job Title										Total
Work. Hours		Architect	CM	H&S Personnel	PM	QS	Civil Engineer	Forman/ Supervisor	Artisan	Construction Worker/Labourer	Other	
56+ hrs	Count	0	1	1	0	0	2	0	1	7	0	12
	% within Number of working hours	0,0%	8,3%	8,3%	0,0%	0,0%	16,7%	0,0%	8,3%	58,3%	0,0%	100,0%
	% of Total	0,0%	0,5%	0,5%	0,0%	0,0%	1,0%	0,0%	0,5%	3,5%	0,0%	6,0%
Between 46-55 hrs	Count	2	3	3	2	5	2	5	3	48	1	74
	% within Number of working hours	2,7%	4,1%	4,1%	2,7%	6,8%	2,7%	6,8%	4,1%	64,9%	1,4%	100,0%

	% of Total	1,0%	1,5%	1,5%	1,0%	2,5%	1,0%	2,5%	1,5%	23,9%	0,5%	36,8%
Between 0 - 45 hrs	Count	2	3	6	3	6	2	10	11	69	3	115
	% within Number of working hours	1,7%	2,6%	5,2%	2,6%	5,2%	1,7%	8,7%	9,6%	60,0%	2,6%	100,0%
	% of Total	1,0%	1,5%	3,0%	1,5%	3,0%	1,0%	5,0%	5,5%	34,3%	1,5%	57,2%
Total	Count	4	7	10	5	11	6	15	15	124	4	201
	% within Number of working hours	2,0%	3,5%	5,0%	2,5%	5,5%	3,0%	7,5%	7,5%	61,7%	2,0%	100,0%
	% of Total	2,0%	3,5%	5,0%	2,5%	5,5%	3,0%	7,5%	7,5%	61,7%	2,0%	100,0%

3.3 Data Interpretation

Table 5 presents the data range interpretation based on the 5-point Likert scales used in the study. The group interval coefficient value for the 5-point Likert scale was calculated as (5) / 3 = 1.67. The range interpretations for the 5-point Likert scale were used in Table 4-5. For further ease of interpretation, the mean values for the 5-point Likert scale were interpreted as; high, medium and low.

Table 5. Data Interpretation Ranges

Range	5-Point Likert Scale	
	Agreement Scale	Ease of interpretation
5.00 - 3.34	Strongly Agree	High (H)
	Agree	
3.33 – 1.68	Neutral/Unsure	Medium (M)
≤1.67	Disagree	Low (L)
	Strongly Disagree	

3.4 Data Analysis

In Table 6 the respondents were presented with 23 statements based on literature about the most prevalent task demands that lead to job stress. Although several working conditions lead to distress, only 23 statements were selected because they were the most prevalent in most studies (Christodoulou, 2021; Tijani et al., 2020; Chan et al., 2021). Therefore, the respondents were requested to indicate their level of agreement on working conditions leading to psychological stressors based on a 5-point Likert scale where 1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree and 5=Strongly Agree.

Table 6. Task Demands

	Mean	Std. Deviation	Rank	
My input is valued at work	3,71	1,172	1	H
I multitask	3,63	1,165	2	H
I get support from my organisation to do work	3,62	1,132	3	H
I have enough resources/tools to help me do my work	3,57	1,150	4	H
My organisation has internal policies which prohibit any form of discrimination	3,44	1,157	5	H
I work under strict discipline and authority by management	3,42	1,151	6	H

Instances of alleged bullying are taken seriously by management	3,40	1,177	7	H
My organisation promotes equality	3,39	1,169	8	H
I worry about my job insecurity	3,34	1,180	9	H
There is too much workload	3,30	1,114	10	M
I work with tight timelines	3,17	1,181	11	M
It is easy to talk back to my boss	3,14	1,269	12	M
My boss is confrontational	3,13	1,210	13	M
There is too much bureaucracy at work	3,05	1,075	14	M
I work long hours	3,03	1,250	15	M
There is lack of innovation in the workplace	2,87	1,149	16	M
I am afraid of my boss	2,84	1,248	17	M
There is poor communication on how to execute tasks	2,84	1,243	18	M
I receive unfair job assignments that are not part of my job description	2,66	1,278	19	M
I feel like I am being looked down upon because of my race	2,56	1,304	20	M
I do not have sufficient knowledge about the project	2,53	1,298	21	M
I feel like I am being belittled because of my gender	2,48	1,269	22	M
I am not given enough work to do	2,47	1,242	23	M

The findings in Table 6 revealed high levels of agreement for statements my input is valued at work (mean=3.71), getting support from organisation to do work (mean=3.62), getting enough resources (mean=3.57), having internal policies against any form of discrimination (mean=3.44), prevention of bullying (mean=3.40) and promotion of equality (mean=3.39). This indicates a good organisational culture. Although the overall responses were good, they are still far from satisfactory. Contrarily, factors of concern with high levels of agreement were multi-tasking (mean=3.63), strict workplace environment (mean=3.42) and job insecurity (mean=3.34).

While some responses were highly ranked, some receive medium response rate. Responses receiving medium level of response were too much workload (mean=3.30), working within tight timelines (mean=3.17), ease of communicating with superiors (mean=3.14), confrontational boss (mean=3.13), bureaucracy (mean=3.05), long working hours (mean=3.03), lack of motivation at work (mean=2.87), afraid of boss and poor communication (mean=2.84), unfair job assignment (mean=2.66), discrimination by race (mean=2.56), insufficient project knowledge (mean=2.53), gender discrimination (mean=2.48) and work under load (mean=2.47).

4. Discussion

Contrary to exception, the findings of this study were not consistent with most literature finding especially in relation to organisational culture. Most workers felt valued at work, received support and resources from the organisation to do work, had internal policies against any form of discrimination and there was prevention of bullying and promotion of equality. However, with multi-tasking and job insecurity the findings were consistent with most literature and a systematic review conducted by Tijani et al. (2020) (from 1997 to 2020) and Chan et al. (2021) (from 1992 to 2020) about the causes of occupational stress in construction. Job insecurity has been linked to financial stress. Most construction workers in South Africa are bread winners which means they support not only their immediate families but also, extended families. Financial stress has been linked to suicide among the workers (Martin et al., 2016) and occurs when these individuals are unable to meet their financial obligations. inability to meet financial obligations as a result of job insecurity leads to esteem issues and feelings of inadequacy. Hobfall (1989) postulated the Conservation of Resources (COR) theory which assumes that stress occurs in any of three situations identified as when people experience loss of resources, when resources are threatened and when individuals invest their resources without subsequent gain. Therefore, the premise of COR theory maintains that individuals are in constant pursuit to acquire, preserve, nurture, and safeguard the things they value (Hobfoll et al., 2018; Hobfoll, 1996). This is true for job insecurity which leads to financial stress. Workers may not be able to meet their basic financial obligations.

Further, multi-tasking leads to cognitive distractions and this can be attributed to the distraction theory which posits that workers have a higher probability achieving a specific task when their attention is focused, and distractions are minimal (Hinze, 1997). Workers in a distracted state may not recognise hazards easily and this not only hinders productivity but leads to accidents on construction sites. Although task demands such as long working hours and work overload which are attributed to tight deadlines were the most prevalent causes of occupational stress among the respondents in our previous study (Raliile et al., 2022) and literature, the current study revealed that they not much of a concern. Furthermore, contrary to previous studies on the lack of support by management, this study revealed that they did receive support from their superiors although not fully. While this was the case with our previous study, the current study sheds more light due to the larger sample size employed. Therefore, it may be inferred from these findings, a positive organisational culture mitigated the effects of other task demands or workers have adapted to the work condition. This requires further investigation by conducting a mixed method study.

5. Conclusions

This study examined task demand stressors that contribute to occupational stress among the workers in the South African construction industry. The research reveals new findings which contradict previous findings and contributes to an understanding of how the workforce is affected by occupational stress in a developing country. However, several limitations need to be acknowledged. The type of sampling used in the study faces challenges associated with self-report questionnaires such as response bias, social desirability, introspective ability, understanding and limitations with rating scales. Future research should validate the questionnaires for any violation of assumptions using EFA and determine the validity of the instrument. Only face validity was conducted for the current study. Further, future research could focus on conducting a mixed method study to gain an in-depth understanding of some of the responses. This exploratory study contributed to existing knowledge by examining task demands that impact worker psychological health. These findings are important in revealing specific areas of concern among the workforce and for informing intervention.

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Critical Challenges of Quality Assurance of Cross-border Construction Logistics and Supply Chain During COVID-19 Pandemic: An International Expert Survey

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Abstract

Quality Assurance (QA) is a critical tool for the success of projects under cross-border construction logistics and supply chain (Cb-CLSC). However, the coronavirus (COVID-19) pandemic has imposed challenges that have affected the adequacy of QA of Cb-CLSC, and this has received limited attention in scholarly reports. Thus, this study aims to identify the critical challenges of QA of Cb-CLSC amid the pandemic by conducting an international expert survey with 102 experts across 25 economies/countries. Sentiment analysis is performed further to understand how the critical challenges have influenced the QA of Cb-CLSC using the negative-neutral-positive model. The study's finding identified ten critical challenges of QA of Cb-CLSC amid the COVID-19 pandemic, with the top five critical challenges comprising "shortage of raw construction material", "changes in work practices", "halting of operations and site closure", "heavy workloads and shortage of construction workers", and "design changes". Aside from the negativity imposed by the pandemic, the sentiments on each critical challenge portrayed positivity and neutrality that empowers the industry, denoting that the pandemic comes with opportunities that may be harnessed to position the QA of Cb-CLSC to be adequate for the post-pandemic era and endure the risks of future pandemics. This study contributes theoretically and practically by identifying and creating awareness of the critical challenges of the QA of Cb-CLSC. This could help practitioners, researchers, and policymakers develop a resilience framework based on innovative management strategies to position the QA of Cb-CLSC adequately for the post-pandemic era and endure the risks of future pandemics.

Keywords

COVID-19, Critical Challenges, Cross-border Construction Logistics and Supply Chain, Sentiment Analysis, Quality Assurance

1. Introduction

Cross-border Construction Logistics and Supply Chain (Cb-CLSC) consists of the interrelated activities and processes engaging contractors, suppliers, or vendors between countries/economies where one performs construction services in the other country/economy (Mawhinney, 2008). Assuring the quality of projects, termed quality assurance (QA), is a critical tool for the success of projects under Cb-CLSC as it guarantees confidence in the projects to meet pre-stated quality standards and perform satisfactorily during the entire service life (International Organisation for Standardisation [ISO], 1994). However, the complexity of performing QA of Cb-CLSC has worsened due to the coronavirus (COVID-19), which was introduced as a pandemic in March 2020 (World Health Organisation [WHO], 2020). Though COVID-19 mitigation measures have helped achieve steady recovery (Office for National Statistics [ONS], 2021; Eurostat, 2022), they have also impeded the movement between countries/borders/economies during QA of Cb-CLSC; hence, disrupting the construction supply chain. This is due to the stringent mitigation measures, including, e.g., social distancing, Lockdown, travelling restrictions, and limited workplace capacity (Organization for Economic Co-operation and Development [OECD], 2020). This has affected the quality of work performed on construction sites toward the overall project quality. For example, relating the quality of construction products to construction output, the ONS (2021) recorded a fall of 12.5% in construction output in 2020 compared with 2019.

The academia, in collaboration with the industry, has reported on the impact of COVID-19 on the construction industry from several perspectives. For instance, studies, including Ogunnusi et al. (2021), Raoufi and Fayek (2022), Dobrucali et al. (2022), and Kukoyi et al. (2022) identified the challenges imposed by the pandemic on the construction industry, but they focused on the general construction industry, which consists of several areas which have experienced unique challenges imposed by the pandemic. As such, Pamidimukkala et al. (2021) considered the impact of the pandemic on the construction health and safety of the workforce and identified the unique challenges but was based on conceptual analysis. Another critical area in construction to consider amid the pandemic is QA, and this has received limited attention. For instance, Ghansah et al. (2022) investigated how COVID-19 mitigation measures have impacted the QA of Cb-CLSC by performing a conceptual analysis. However, the unique critical challenges of the QA of Cb-CLSC amid the pandemic were not clearly explored. Meanwhile, identifying these critical challenges could contribute to developing a resilience framework to position the QA of Cb-CLSC to be adequate for the post-pandemic era and endure the risks of future pandemics.

This study, therefore, aims to empirically identify the critical challenges of QA of Cb-CLSC amid the COVID-19 pandemic by conducting an international expert survey across the globe. Sentiment analysis is performed further to understand how the critical challenges have influenced the QA of Cb-CLSC using the negative-neutral-positive model. The findings of this study could assist the practitioners and policymakers in developing a resilience framework capable of positioning the QA of Cb-CSLC adequately for the post-pandemic era and enduring the risks of future pandemics. This study also contributes to knowledge by identifying the critical challenges of QA of Cb-CLSC amid the pandemic and their associated sentiments. This may guide researchers to study QA in the construction industry further and suggest ways to improve the tool to survive future pandemics.

2. Brief Overview of COVID-19 on QA of Cb-CLSC

Conducting QA of Cb-CLSC depends on an organisation's quality management system, which embraces organisational resources, structure, and procedures (ISO, 1994). Integrating QA into the construction processes of organisations in Cb-CLSC regulates the processes' conduct and prevents side-stepping or deviation from quality requirements (Chung, 2002). QA of Cb-CLSC has been the responsibility of the contractor, consultant, designer, and government-authorised agencies. Hence, a concerted effort is central to ensuring an effective QA of Cb-CLSC by ensuring that everyone in the organisation knows what they are expected to do and what their colleagues are doing (Chung, 2002). In the case of the Cb-CLSC, the consultant, the client representative, and the government-authorised agency may need to travel offshore to foresee the quality of construction projects. Such a case has been the modular construction, specifically between Guangdong Province of China and Hong Kong, where authorised and client representatives are dispatched offshore to verify and accept the quality of modular components (Lu et al., 2022).

The construction industry is noted to be significantly affected by COVID-19, especially the QA processes, putting experts at high risk of severe infections. Baker et al. (2020) reported that, in April 2020, 8.3% of the 5.9 million construction workers, including QA teams, etc., were exposed once a month during the pandemic. Subsequently, this led to delays and suspension, cancellation of projects, supply chain disruption, creation of new risks, etc. This has raised a greater consent on QA of Cb-CLSC, which engages contractors and other professionals between countries/borders/economies where one performs services in the other country/economy. As such, the unique challenges imposed by the pandemic can be identified to inform decision-making in developing a resilience framework capable of positioning the QA to be adequate for the post-pandemic era and endure the risks of future pandemics.

3. Research method

The study adopted a quantitative research design following four research processes, as illustrated comprehensively in Figure 1. After a comprehensive desk literature review through google scholar, web of science, and Scopus (Ghansah et al., 2022), the identified potential challenges (18) were further refined by conducting a pilot test with experts, which helped settle on ten potential challenges, as shown in Table 1. These were finally presented to the experts across the globe via an online expert survey (using *QUALTRIC XM*) to respond to the questionnaire using the Likert scale: level of agreement (1=Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree) and level of sentiment (1=Negative; 2=Neutral; 3=Positive). The population included experts from academia and the industry who are knowledgeable about QA processes in construction. Due to the lack of a recognisable database consisting of the population, the study adopted purposive sampling and snowball sampling techniques. As a result, experts were contacted via the Linkedin platform, email addresses, and company websites. Subsequently, after three months of data collection, 102 experts' responses were collected online across different countries/borders/economies.

Table 1: Potential challenges of QA of Cb-CLSC amid the pandemic

Code	Challenges	References
C1	Collaboration and communication difficulties	Oo et al. (2021); Rankohi et al. (2022)
C2	Long approval process and schedule delays	Oey and Lim (2021); Aigbavboa et al. (2022); Dobrucali et al. (2022) Rankohi et al. (2022); Olatunde et al. (2022); Rehman et al. (2022)
C3	Heavy workloads and shortage of skilled construction workers	Pamidimukkala et al. (2021); Oo et al. (2021)
C4	Legal issues due to a breach of contract terms and conditions	Bsisu (2020), Husien et al. (2021); Amoah et al. (2021); Radzi et al. (2022) Rankohi et al. (2022); Umar (2022)
C5	Working with masks difficulties	Oey and Lim (2021)
C6	Design changes	Oey and Lim (2021); Simpeh et al. (2022); Rankohi et al. (2022)
C7	Shortage of raw construction material	Rankohi et al. (2022); Jeon et al. (2022); Al-Mhdawi et al. (2022); King et al. (2022); Agyekum et al. (2022)
C8	Halting of operations and site closure	Rankohi et al. (2022); Aigbavboa et al. (2022)
C9	Rising cost of construction materials	Ogunnusi et al. (2021); Husien et al. (2021); Rehman et al. (2022)
C10	Changes in work practices	Oey and Lim (2021); Simpeh et al. (2022); Rankohi et al. (2022).

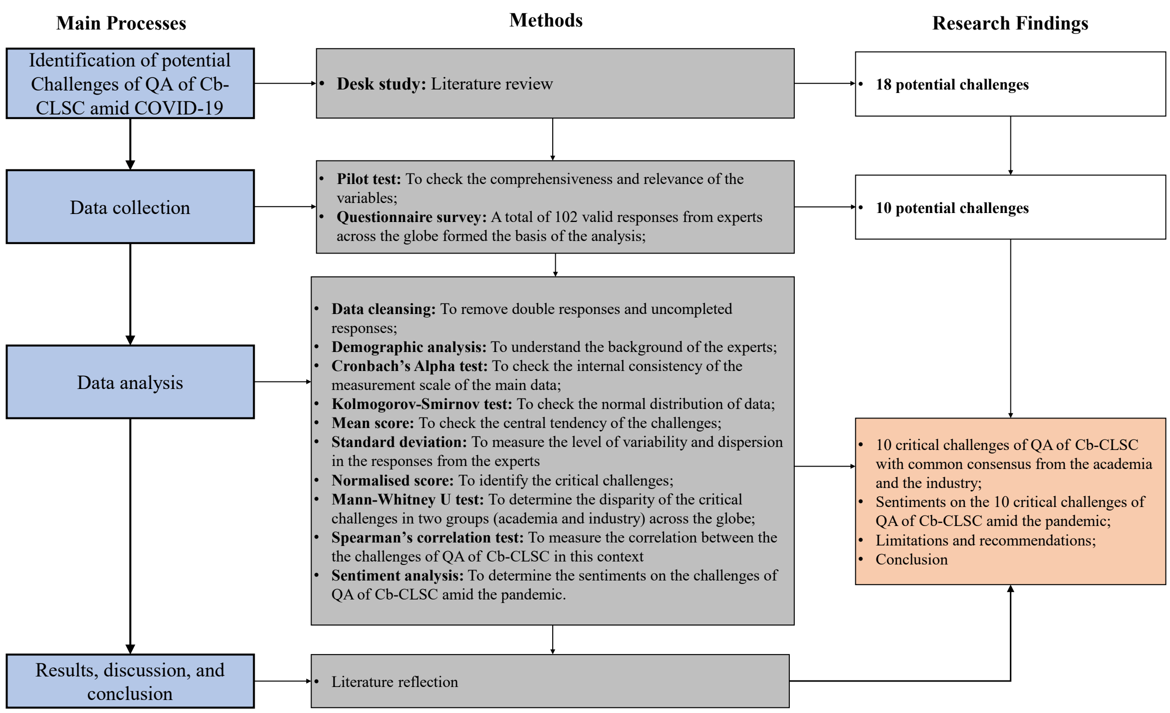

Figure 1: Research Flow

4. Data Analysis and Results

4.1 Analysis of Demographic Data

Figure 2 shows the countries/economies involved in the expert survey, with Ghana(n=37) having the most responses, followed by the United States of America (n=13). Twenty-five (25) countries/economies participated in the expert survey, and the responses were fairly generated across the continents, involving experts with backgrounds as detailed and analysed in Table 2.

Table 2: Experts' Profile

Variables	Frequency	Percentage (%)	Cumulative percentage (%)
Qualifications			
Bachelor of science (BSc)	12	11.8	11.8
Masters of Science/Philosophy (MSc/MPhil)	49	48.0	59.8

Doctor of Philosophy (PhD)	34	33.3	93.1
Other[a]	7	6.9	100.0
Sector			
Academia	47	46.1	46.1
Industry	55	53.9	100.0
Nature of Organisation			
Contractor	18	17.6	17.6
Consultancy	27	26.5	44.1
Academia	42	41.2	85.3
Other[b]	15	14.7	100.0
Total	**102**		
Profession			
Academician	45	44.1	44.1
Quality Auditor	2	2.0	46.1
Quality Engineer	10	9.8	55.9
Quality Control Manger	3	2.9	58.8
Authorised person from the government	3	2.9	61.8
Client representative	14	13.7	75.5
Other[c]	25	24.5	100.0
Experience			
Less than 5 years	45	44.1	44.1
5-10 years	25	24.5	68.6
11-20 years	23	22.5	91.2
21-30 years	3	2.9	94.1
More than 30 years	6	5.9	100.0

Other[a] may consist of other qualifications such as Higher Diploma certificate, and others
Other[b] may consist of government agency, etc.
Other[c] may consist of other experts essential in the QA process, including the construction and project managers

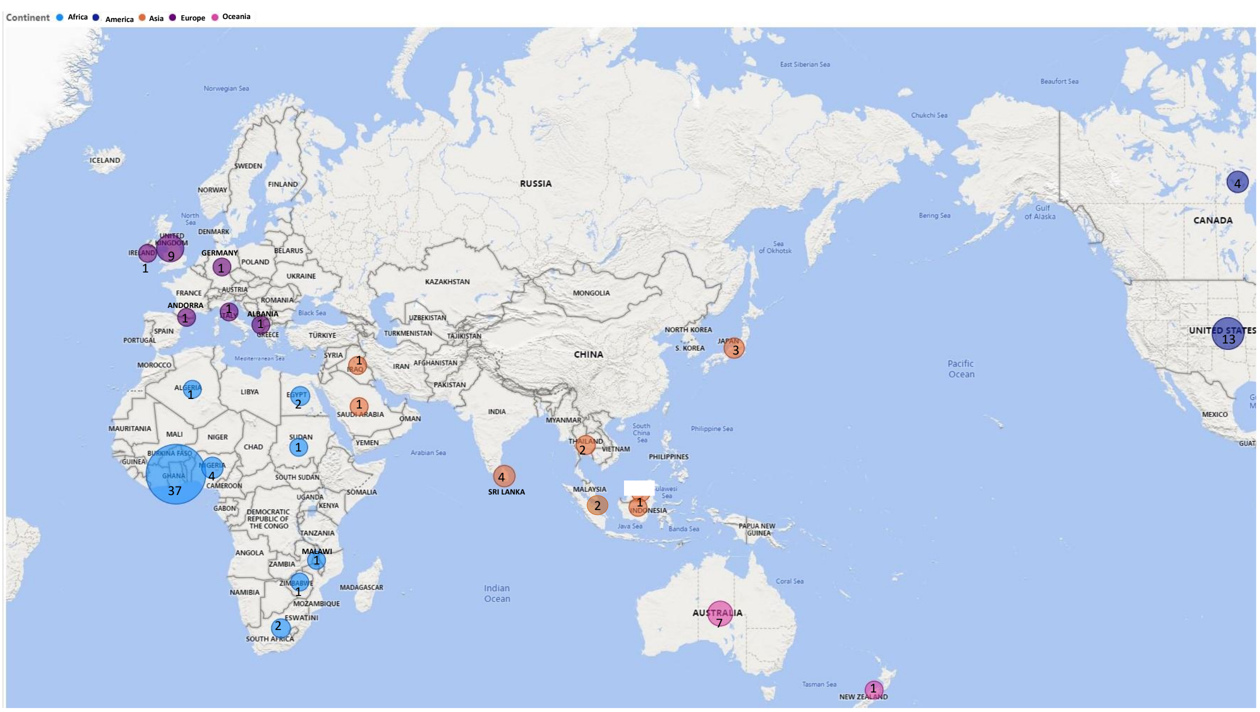

Figure 2: Participating Countries/Economies

Table 3: Normality Test, Descriptive Test, Level of Criticality test, and Differential Test

Code	Overall				Industry			Academia			K-S			Mann-Whitney U		
	Mean	SD	Ns	Rank	Mean	SD	Ns	Mean	SD	Ns	K-S stat.	P-value	U stat.	W	Z	P-value
C1	3.84	1.02	0.71[a]	9	3.76	1.07	0.69	3.94	0.97	0.65	0.28	0.00	1192.50	2732.50	-0.71	0.49
C2	4.14	0.81	0.71[a]	8	4.11	0.85	0.70[a]	4.17	0.76	0.59	0.24	0.00	1262.50	2802.50	-0.22	0.83
C3	4.01	1.19	0.75	4	3.80	1.25	0.70[a]	4.26	1.07	0.82	0.32	0.00	982.00	2522.00	-2.23	0.03***
C4	3.53	1.92	0.63	10	3.45	1.15	0.61	3.62	1.24	0.66	0.19	0.00	1188.50	2728.50	-0.72	0.47
C5	3.86	1.03	0.72	6	3.89	0.92	0.63	3.83	1.17	0.71	0.24	0.00	1282.00	2822.00	-0.07	0.94
C6	3.90	0.93	0.73	5	3.87	0.94	0.62	3.94	0.92	0.74	0.20	0.00	1243.50	2783.50	-0.35	0.73
C7	4.37	0.87	0.79	1	4.25	0.95	0.75[a]	4.51	0.75	0.84	0.33	0.00	1101.00	2641.00	-1.45	0.15
C8	4.51	0.63	0.75	3	4.49	0.61	0.75[a]	4.53	0.65	0.77	0.36	0.00	1223.00	2763.00	-0.53	0.59
C9	4.41	0.75	0.71[a]	7	4.45	0.72	0.73	4.36	0.79	0.68	0.35	0.00	1225.50	2353.50	-0.51	0.61
C10	4.10	0.91	0.77	2	4.16	0.81	0.72	4.02	1.01	0.76	0.238	0.00	1221.50	2349.50	-0.51	0.61

Note: Ns=Normalisation score=(actual mean–minimum mean)/(maximum mean-minimum mean), only normalisation scores ≥0.5 are deemed critical by the experts; SD=Standard deviation; W=Wilcoxon; Ranking based on the normalised score; P-value (Asymp. Sig. (2-tailed)≤0.05; degree of freedom for KS(df)=102 for all variables; [a]Equal normalised score, wherein challenges with low SD is ranked higher; ***challenge with p-value less than 0.05; H_o rejected, K-S= Kolmogorove-Smirnov[a]

Table 4: Spearman's Correlation Test and Sentiment analysis

Code	Spearman's Correlation										Sentiment Analysis				
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Negative (%)	Neutral (%)	Positive (%)	Sentiment score	P-values
C1 P-value	1.000 -										54.90	32.40	12.70	1.58	0.66
C2 P-value	0.403** 0.000	1.000 -									61.80	22.50	15.70	1.54	0.56
C3 P-value	0.490** 0.000	0.647** 0.000	1.000 -								60.80	26.50	12.70	1.52	0.59
C4 P-value	0.536** 0.000	0.511** 0.000	0.604** 0.000	1.000 -							33.30	49.00	17.60	1.84	0.63
C5 P-value	0.539** 0.000	0.453** 0.000	0.702** 0.000	0.573** 0.000	1.000 -						54.90	31.40	13.70	1.59	0.61
C6 P-value	0.556** 0.000	0.321** 0.001	0.365** 0.000	0.421** 0.000	0.331** 0.001	1.000 -					47.10	42.20	10.80	1.64	0.32
C7 P-value	0.320** 0.001	0.297** 0.002	0.467** 0.000	0.273** 0.005	0.526** 0.000	0.602** 0.000	1.000 -				62.70	22.50	14.80	1.52	0.86
C8 P-value	0.352** 0.000	0.176 0.076	0.149 0.134	-0.009 0.929	0.173 0.082	0.323** 0.001	0.446** 0.000	1.000 -			55.90	12.70	31.40	1.75	0.62
C9 P-value	0.459** 0.000	0.337** 0.001	0.354** 0.000	0.187 0.059	0.408** 0.000	0.526** 0.000	0.515** 0.000	0.575** 0.000	1.000 -		53.90	32.40	13.70	1.60	0.89
C10 P-value	0.306** 0.002	0.546** 0.000	0.465** 0.000	0.307** 0.002	0.537** 0.000	0.178 0.073	0.275** 0.005	0.195* 0.050	0.418** 0.000	1.000 -	42.20	29.40	28.40	1.86	0.52

P-values based on the Mann-Whitney U test to check the degree of association between the sentiments based on the two groups (academia and industry); ρ=correlation coefficient; **correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed).

4.2 Analysis of Main Data

The internal consistency of the data was determined first by Cronbach's Alpha (CA) following the thumb rule by Pallant (2001): CA value <0.60 is unacceptable, 0.60-0.80 is moderate and acceptable, and 0.80-1.00 shows excellent and higher internal consistency and validity of the data. The CA value for this study was estimated to be 0.87 for the level of agreement and 0.90 for the level of sentiment, connoting high internal consistency among the datasets. The Kolmogorov-Smirnov (K-S) adopted for this study denoted the dataset not to be normally distributed largely; hence, the dataset was deemed non-parametric. The central tendency of the challenges was measured using the means score, whilst the degree of variation among the experts' responses was determined using the standard deviation. The level of criticality of the challenges was then determined by using the normalisation scores following the thumb rule: normalised scores ≥0.50 are considered more critical (Adabre et al., 2020). Mann-Whitney U (MWU) test was then conducted to assess the degree of association among the experts' responses to the critical challenges based on their level of agreement from the viewpoints of academia and the industry (differential test). With this, a null hypothesis, H_0, is that there is no significant difference vis-à-vis the level of agreement on the critical challenges among academia and industry. The H_0 can be rejected if P-value is ≤0.05. The results are shown in Table 3.

Spearman's correlation test was conducted due to the non-parametric nature of the dataset to measure how the critical challenges correlated among themselves based on experts' responses, following the thumb rule: +1=perfect positive correlation, -1=perfect negative correlation, situated at a statistical significance of p-value≤0.05. Sentiment analysis was finally conducted to understand the influence of the challenges on the QA of Cb-CLSC based on the experts' views using the negative-neutral-positive model (Ferrara and Yang, 2015), as shown in Table 3. The sentiment scores are estimated to determine the central tendency of the critical challenges in terms of sentiment level using the mean score. Finally, the degree of association between the sentiments on the critical challenges from experts in academia and industry is determined using the MWU test, setting a null hypothesis, H0, that there is no significant difference in the sentiments as responded by the experts from academia and industry. For the results, refer to Table 4.

5. Discussion of Results

The COVID-19 pandemic has disrupted the QA of Cb-CLSC by imposing challenges, making the QA processes difficult and cumbersome for experts. The study has then revealed the critical challenges of the QA of Cb-CLSC amid the pandemic, which has been missing from recent scholarly reports. The findings revealed that the associated challenges facing the QA of Cb-CLSC amid the pandemic include the challenges coded C1 to C10. Based on the mean score, the challenge having the highest value representing the central tendency of the experts is "halting of operations and site closure (C8)" (means score=4.51), followed by "rising cost of construction materials (C9)" (means score=4.41) and "long approval process and schedule delays (C2)" (means score=4.14). However, the mean score analysis does not identify the critical challenges. By estimating the normalisation scores for each challenge, the study identified the critical challenges of QA of Cb-CLSC following the thumb rule by Adabre et al. (2020). The study revealed all ten challenges to be critical. However, the top five critical challenges that need to be given attention by experts include "shortage of raw construction material (C7)" (score=0.79), "changes in work practices (C10)" (score=0.77), "halting of operations and site closure (C8)" (score=0.75), "heavy workloads and shortage of construction workers (C3)" (score=0.75), and "design changes (C6)" (score=0.73). The disruptions in the construction supply chain due to the pandemic cause a reduction/shortage in the raw construction material supply due to the multiple national lockdowns (Al-Mhdawi et al., 2022; King et al., 2022). The disruption occurs at the upstream supply chain, which may cause delays in the flow of construction materials to sit, halting the construction works till materials are available on site (Rankohi et al., 2022). This then affects the QA processes because the project may be delayed until the quality auditors carry out their functions, or they may rush to audit works quickly, which may be associated with errors because of speedy work delivery. The result of this study then affirms the study by Rankohi et al. (2022) and Jeon et al. (2022) when they revealed the shortage of materials on sites as a major challenge in the construction industry amid the pandemic. Also, from the individual sector perspective, the experts in academia regard the "shortage of raw construction material" as the most critical challenge, while the industry considers the "shortage of raw construction material" alongside "halting of operations and site closure". Subsequently, the study makes a proposition that the top most critical challenge of QA of Cb-CLSC is the "shortage of raw construction material", and this can replicate to cause other critical challenges, such as "halting of operations and site closure" and "changes in work practices". Overall, all the challenges (C1-C10) can be regarded as critical in impacting the QA of Cb-CLSC.

A further analysis using the Mann-Whitney U test denoted that the experts from academia and industry have no differences on the critical challenges except for the "heavy workloads and shortage of skilled construction workers" (C3) (P-value=0.03). This may be because the industry may regard C3 as a critical challenge of QA of Cb-CLSC amid the pandemic, but academia may have a different perspective on C3. From different perspectives, it is important to acknowledge that during the pandemic, the number of workers on construction sites was cut off compared to the typically required number due to the COVID-19 mitigation strategies such as social distancing on sites and the required number of workers in a workplace (Minett, 2020; Raoufi and Fayek, 2022). This affects the QA because it is process-oriented and requires the collective efforts of all skilled workers, not only the front-liners. Once there is a shortage of skilled workers on cross-border construction projects, there is a higher possibility of an error occurring on a project due to a lack of regular quality inspections and auditing of construction works, especially when it involves travel across borders. The pandemic mitigation measures may restrict skilled workers or experts from travelling to different countries/economies/borders to audit and verify the quality of construction services and works executed. The use of Spearman's correlation test revealed a relatively fair positive correlation among the critical challenges, except between "legal issues due to a breach of contract terms and conditions (C4)" and "halting of operations and site closure (C8)" ($\rho=-0.009$, $p>0.05$); which showed a negative correlation but insignificant. The highest significant positive correlation exists between "working with masks difficulties (C5)" and "heavy workloads and shortage of skilled construction workers (C3)" ($\rho=0.702$, $p<0.05$), depicting experts are not convenient with working with nose/face masks on as they are faced with breathing issues, especially during auditing and inspection of the quality of works executed or services. Such inconvenience may cause worker absence, and gradually heavy workloads may set in, which may cause stress to the remaining workers (Oo et al., 2021; Oey and Lim, 2021), probably leading to human errors affecting the quality of projects. Management may control this by providing a safe environment to encourage and protect workers throughout the QA process in construction.

Based on the sentiment analysis, the study makes a proposition that the sentiments of the challenges imposed by COVID-19 on the QA of Cb-CLSC have not been entirely negative but have also positioned the construction industry in terms of the adoption of digital technology and innovative management strategies. The challenges have been largely negative, as obvious, but there are also positive sides, as well as the neutral side. For instance, "shortage of raw construction material" has been the challenge with the highest level of sentiment (62.70%). This can be attributed to heavy disruption to the construction supply chain and the auditing of such material to ensure quality (Rankohi et al., 2022; Jeon et al., 2022). However, there have been a neutral sentiment (22.50%) and positive sentiment (14.80%), which can be related to the experts adopting innovative management strategies enabled by digital technologies to ensure adequate QA of Cb-CLSC (Elabd et al., 2020; Lu et al., 2022). This can be confirmed by the fairly distributed sentiment scores >1.50 depicting the sentiment not to be only negative when compared to the model adopted: 1=Negative; 2=Neutral; 3=Positive. Using the Mann-Whitney U test, this sentiment level attained depicts no significant differences between the sentiments from the two groups of experts (academia and industry). Overall, the sentiments on each challenge portray positivity and neutrality that empowers the industry, especially in the field of QA. This denotes that the pandemic comes with opportunities, and the industry may harness these to position the QA of Cb-CLSC to be adequate for the post-pandemic era and endure the risks of future pandemics.

6. Conclusion

From this study, the QA of Cb-CLSC has been impacted by the COVID-19 pandemic imposing critical challenges, with the top five being "shortage of raw construction material", "changes in work practices", "halting of operations and site closure", "heavy workloads and shortage of construction workers", and "design changes". Apart from the negative sentiments, each of the critical challenges also portrayed positivity and neutrality that empowers the industry, denoting that the pandemic comes with opportunities, and the industry can harness these to position the QA of Cb-CLSC to be adequate for the post-pandemic era and endure the risks of future pandemics.

Despite the findings, the study has limitations that need to be acknowledged during the result interpretation and generalisation. The study's outcome relied on 25 economies/countries, which is relatively less than the number of economies across the globe. Hence, future studies can research specific economies not involved in this study to identify some critical challenges and explore the opportunities believed to be created by the COVID-19 pandemic toward positioning the QA of Cb-CLSC to be adequate amid future pandemics. This may also reveal more insights. However, the relevance of the study's results remains due to the rigorous analysis conducted.

Notwithstanding the limitations, the study contributes theoretically to the literature on QA and Cb-CLSC by identifying the critical challenges of QA of Cb-CLSC amid the COVID-19 pandemic. It also contributes to the lessons learned from the pandemic in the construction industry. This knowledge could direct researchers toward developing a resilience framework to position the QA to be adequate for the post-pandemic era and endure the risks of future pandemics. Practically, this study creates awareness of the critical challenges of QA of Cb-CLSC amid the pandemic to the QA teams and policymakers in construction. This could help industry practitioners and researchers understand the impacts of the pandemic and develop innovative management strategies to position the QA of Cb-CLSC to be adequate for the post-pandemic era and endure the risks of future pandemics.

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Trombe Wall Performance in Multiple Climates: A Simulation Study

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Abstract

Global warming is an increasing concern worldwide, with energy production enhancement being one of the contributing factors. By 2040, the global energy demand is projected to increase by approximately one-third. This paper proposes a study on the efficiency of implementing a simple Trombe wall structure to passively gain solar energy and heat or cool a space. The methodology involves using computational data on heating and cooling energy loads via simulations in the DesignBuilder software. Fifteen climate zones were selected according to the Koppen-Geiger climate classification map, and appropriate building envelopes and simulations were modeled and conducted. The results were controversial for some climate zones and required further investigation. The simulation data demonstrated the efficiency of the Trombe wall installation in one zone and showed its inappropriateness for another climate classification. The specific composition of the wall, roof, and other building structures is crucial for particular climate zones. Another potential reason for Trombe wall performance being negative in terms of energy-saving parameters in heating-dominant zones is the climate classification issue.

Keywords

Global warming; Climate zones; Passive solar energy gaining system; Trombe wall; Energy efficiency

1. Introduction

In recent times, the energy demand is rapidly increasing in the world. It is significantly linked to urbanization and global warming. The energy loads are predicted to be increased by 37% by 2040 globally (IEI RAS, 2013). It inevitably leads to the release of harmful and health-destructive gases into the environment due to energy generation to maintain the comfortable thermal conditions in building envelopes. The building envelopes use heating, ventilating, and cooling (HVAC) systems to maintain an appropriate level of indoor temperatures. One of the ways to minimize emissions from the buildings is to use passive solar energy systems, particularly the Trombe wall structures, both for heating and cooling purposes (Hu et al, 2017). Trombe wall is a structure usually oriented to the south in the Northern hemisphere and usually of dark color with glazing material to transfer solar radiation inside the building (Fig. 1). It has different consistency but mainly it is made of brick, quarry rock, and reinforced concrete (Saadatin et al, 2012). Incorporating the Trombe wall structures in the building envelopes is one of the strategies leading to sustainable development. The Trombe walls are extremely encouraged to be implemented due to their advantages such as simple configuration, high efficiency, and minimized construction and maintenance costs (Hami et al, 2012).

Rabani et al (2015) investigated the potential of the Trombe wall structure in decreasing the energy load needed for heating and cooling purposes in Yazd city, Iran. A design for the Trombe wall was proposed. Specifically, they invented the Trombe wall with glazing surfaces facing east, south, and west directions. Thus, the modified wall received more solar radiation than the ordinary one and the difference accounted for roughly 16%. Likewise, the energy storage of the Trombe wall increased. It achieved 5800 kJ/h in February of energy stored.

Jaber and Ajib (2011) investigated the performance of the Trombe wall for a residential building located in the Mediterranean region. The energy simulations were done by TRNSYS software and the optimum Trombe wall area ratio as a function of the economic and thermal parameters was designed. The Trombe wall structure had the classical configuration used for heating purposes in the Amman region of the Mediterranean region. The prototype building was modeled using ASHRAE Standard 62.2. As a result, after completing simulations, it was calculated that roughly 20% of the annual heating load could be saved by implementing the Trombe wall structure when it was embedded into two bedrooms facing the South facade. Moreover, they reported that the additional embedment of a

Trombe wall to the guest room with two bedrooms increased the savings to 27% of the annual heating energy load. By examining the effect of the Trombe wall ratio on the energy performance, it was inferred that the optimum wall ratio is 37% for the particular building prototype. However, the conclusion implies that the availability of solar radiation plays a big role in the performance of the Trombe wall. Precisely, the higher the solar radiation, the less amount of heating energy is needed to maintain comfort conditions in the building envelope.

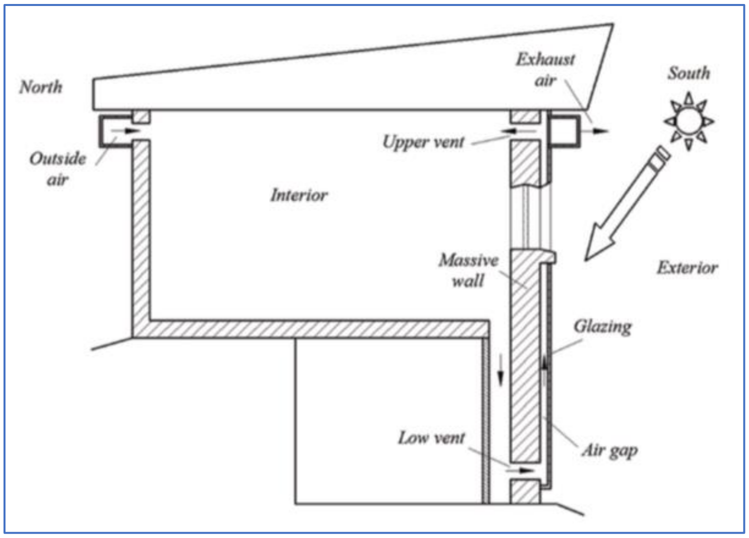

Fig. 1. Simple Trombe wall (Trombe and Michel, 1972).

This research is going to investigate the extent to which the installation of the Trombe wall structure is efficient in diminishing the energy consumption rate of buildings in different climate zones. The abbreviation and location of borderlines for climate zones are presented in Koppen-Geiger updated map (Fig. 2). The question is to be answered by calculating the energy performance of particular building envelopes in selected cities situated in different climate zones. Although Trombe walls are invented at the end of the twentieth century, their energy performance in different climate zones is not studied properly and this research is to fill this gap to some extent. The potential usefulness of this structure is the decline in heating and cooling consumption which could positively affect the environment while decreasing carbon dioxide emissions. Moreover, passive solar energy production does not require the consumption of electricity. The first part of the paper is to design two building envelope models in the DesignBuilder software. Particularly, one is the basic building and another one is modeled using the Trombe wall structure. The second part reports the results of simulations done by the DesignBuilder software. It includes tables and graphs showing the consumption of heating and cooling energy for two building types for the period of 2004-2018. The next part discusses and compares retrieved data with each other. The last part is dedicated to finding the overall trend of efficiency of the Trombe wall structure installation.

2. Methodology

2.1. Koppen-Geiger climate classification map

The selection of cities was done according to the modified Koppen-Geiger classification map (Beck et al, 2018). The research uses the latest version of the Koppen-Geiger climate classification map with a 1 km resolution. This study used a map projected for the present day, particularly for 1980-2016 (Fig. 2). The recent version of the map includes five major climate zones with thirty types of subzones. Zoning is done taking into account the temperature profile and precipitation rate of the specific region. Specifically, the map includes tropical (A), arid (B), temperate (C), cold (D), and polar (E) climates. The following sub-zoning is done following the precipitation rate of location: desert (W), steppe (S), fully humid (f), summer day (s), winter dry (w), and monsoonal (m). Furthermore, the difference in temperature profiles is defined by hot arid (h), cold arid (k), hot summer (a), warm summer (b), cool summer (c), extremely continental (d), and polar frost (F) conditions.

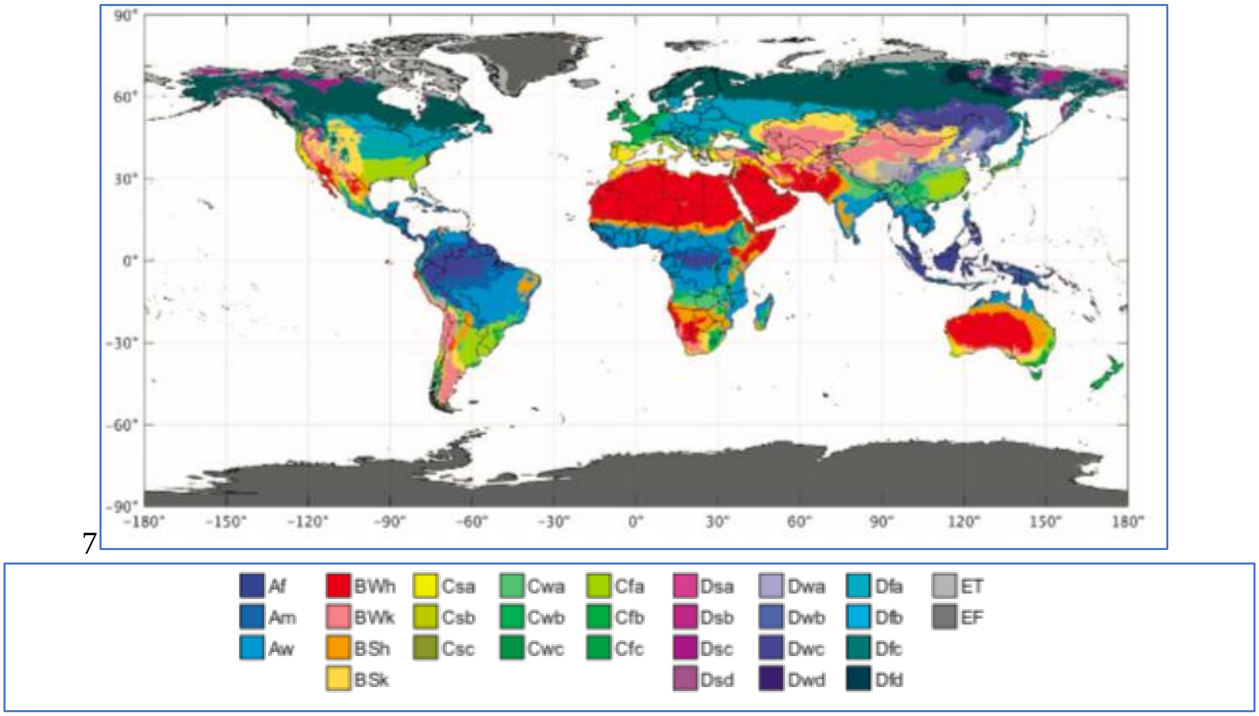

Fig. 2. Koppen-Geiger climate classification map is valid for 1980-2016 (Beck et al, 2018).

2.2. Selection of cities

Three different cities from each climate region were chosen concerning the updated Koppen-Geiger climate map to find the approximate pattern and increase the accuracy of results. Cities are chosen to be not within the boundaries of climate zones to avoid miscalculations in the results of energy consumption. The geographical situation, elevation, and climate classification of each city are represented in Table 2 in the results section.

2.3. Reference buildings

Two different building models were designed in the DesignBuilder software but with the same floor area of 15 m x 15 m dimensions. The floor-to-ceiling height of both buildings is equal to 3.5 m and the chosen window-to-wall ratio accounts for 25%. The window height equals 1.5 m with 5 m spacing between each other. The building is a single-room building that is occupied by a couple of people who go to work every day from 8 am to 7 pm and, subsequently, the occupancy time is designed to be from 7 pm to 8 am during which a couple does not exercise actively. During the occupancy time, they mostly do cook and relax in front of the TV.

The composition of external walls is similar in both envelopes. The visual representation of the wall composition can be found in Fig. 3. The main heat transfer coefficients are convective and radiative are also taken into account and reported in Table 1.

The basic roof structure is chosen in this research. The flat roof is not pitched and the composition and its visual representation are in Fig. 4. The heat transfer coefficients are almost the same as in the external wall structure, particularly it is presented in Table 1.

The following part is to depict the specific composition and designs of buildings without Trombe walls and a building with an incorporated Trombe wall structure.

2.3.1 Basic building envelope

The basic building envelope without a Trombe wall installed is shown in Fig. 5 and is considered to be a single-room box model with eight windows (two windows for each wall). The dimensions of the floor are 15 m x 15 m.

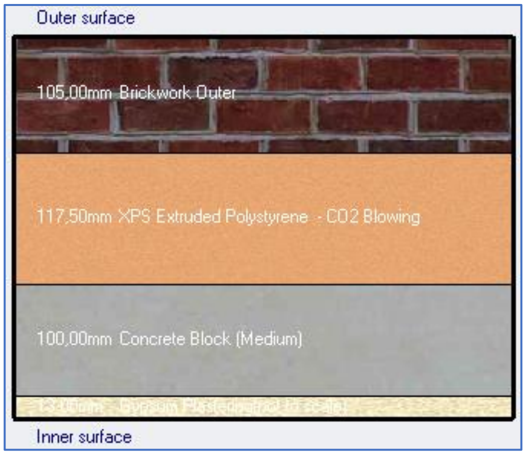

Fig. 3. External wall composition

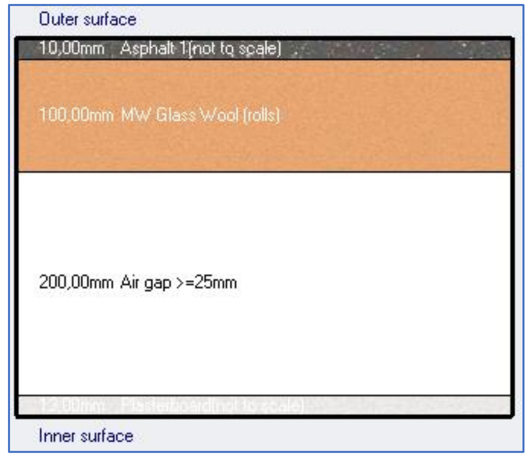

Fig. 4. Flat roof composition

Table 1. Heat transfer coefficients (W/m^2-K) of external wall and flat roof

	External wall and Flat roof	Internal partition wall
Outer surface		
Convective	19.87	2.152
Radiative	5.13	5.54
Inner surface		
Convective	2.152	2.152
Radiative	5.54	5.54

Fig. 5. Rendered view of the building envelope without the Trombe wall

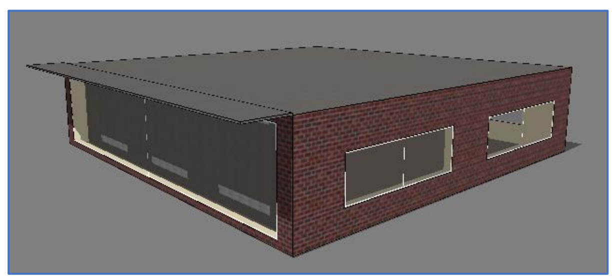

Fig. 6. The rendered view of the building model with Trombe wall

2.3.2. Building envelope with embedded Trombe wall structure

The floor area of living space is lower in the basic building home due to the installation of a Trombe wall, which has a floor area equal to 10.95 m^2, the dimensions are 15 m x 0.73 m (Fig. 6). It was installed instead of one wall, and therefore, the number of windows decreased by two. The Trombe wall is presented in the schematic view in Fig. 7. Taking into account the schematic view, it can be seen that the purple rectangles are the vents. Vents are located at the top and the bottom of the partitioning wall. Air from the bottom three vents is going to circulate and go upward, thus, entering the three upper vents. Each of the vents has a rectangular shape and size of 2.5 m x 0.29 m. Furthermore, the Trombe wall has amended the windows with an outer glazing layer. The dimensions of the glazing surface are 13.85 m x 3 m.

The Trombe wall structure has a shading plate at the top, as the continuation of a flat roof structure. The dimensions of the plate are 15 m x 1.48 m. It is used to protect the building from direct solar radiation during summertime.

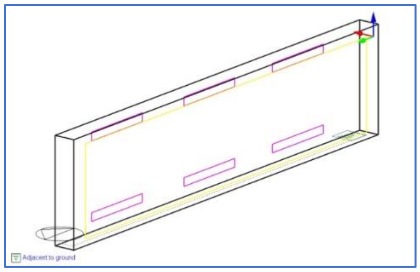

Fig. 7. Schematic view of the Trombe wall

It is determined that at noon of 15 July, the sun is at its peak and no direct sun rays enter the single-room house due to the installed shading plate. Hence, allowing the sun's rays to enter the room during wintertime. Specifically, on 15 December, when the sun is at its peak height over the house, the direct sunlight warms the partition wall of the Trombe wall structure, thereby, increasing the temperature inside the envelope. The internal wall consists of a gypsum plasterboard on its outer surface and an air gap between them (Table 1).

2.4. Energy simulation

One of the potential ways to gauge how the building envelope will be affected by climate change is to look at its energy performance. EnergyPlus software was used to run the simulations with the aid of a reference building that was modeled in DesignBuilder software. EnergyPlus software is operating within the DesignBuilder software to calculate heating, cooling, and annual energy demand in buildings. Properly validated energy simulations are crucial for analyzing the building's heat transfer and changes in energy consumption.

3. Results and Discussions

The hourly weather files needed for performing energy simulations were imported into the software, which was downloaded from the online website climate.onebuilding.org. The hourly weather data then was imported into DesignBuilder software and energy simulations were performed for each climate zone consequently. The results of energy simulations for both the basic building and the building incorporated by the Trombe wall are presented in Table 2.

Table 2. The results for the basic building envelope.

Zone	City	Latitude	Longitude	Elevation (m)	Building without Trombe wall		Building with Trombe wall	
					Heating demand (kWh)	Cooling demand (kWh)	Heating demand (kWh)	Cooling demand (kWh)
Af	Kuala Lumpur, Malaysia	3.1	101.7	66	0	3223	0	3660
	Davao, Philippines	7.1	125.7	18	0	5153	0	5289
	Singapore, Singapore	1.4	103.8	15	0	4060	0	5038
Am	Douala, Cameroon	4	9.7	9	0	21255	0	15935
	Cairns, Australia	-16.9	145.8	8	0	18140	0	14545
	Mumbai, India	19.1	82.9	11	0	17755	0	18556
Aw	Brasilia, Brazil	-15.9	-47.9	1061	0	12679	0	12194
	Caracas, Venezuela	10.5	-66.8	842.8	0	14480	0	14262
	Havana, Cuba	23.2	-82.3	40.2	0	12701	0	17165
BWh	Abu Dhabi, UAE	24.4	54.7	27	0	11819	0	15892
	Cairo, Egypt	30	31.2	23	0	10427	0	7871
	Doha, Qatar	25.3	51.5	7.3	0	16569	0	13145
BSk	Valencia, Spain	39.5	0.5	62	0	3672	0	6543

	Karaganda, Kazakhstan	49.8	73.2	553	6859	0	5395	0
	Tehran, Iran	35.7	51.4	1168.3	0	3214	0	4844
BSh	Lahore, Pakistan	31.5	74.4	217	0	11846	0	8788
	New Delhi, India	28.6	77.2	213.6	0	10252	0	8136
	Tripoli, Libya	32.7	13.1	63	0	9235	0	9221
Cfa	Atlanta, USA	33.7	-84.4	320	3054	4442	0	4002
	Belgrade, Serbia	44.8	20.4	170.3	3032	0	2795	0
	Bucharest, Australia	44.4	26.1	71.6	5512	0	5925	0
Cfb	Amsterdam, Netherlands	52.4	4.9	9.5	3920	0	4300	0
	Bilbao, Spain	43.3	-2.9	39	0	1398	0	4903
	Brussels, Belgium	50.9	4.4	26.7	4102	0	3976	0
Csa	Algiers, Algeria	36.8	3.1	37	0	8511	0	7006
	Athens, Greece	38	23.7	70.3	0	981	0	3904
	Barcelona, Spain	41.4	2.2	9.9	301	0	770	0
Csb	Cannes, France	43.6	7	6.4	0	0	0	4486
	Cape Town, South Africa	-33.9	18.4	14	0	14868	0	15916
	Vancouver, Canada	49.3	-123.1	32	0	4052	0	5034
Cwa	Hanoi, Vietnam	21	105.8	15.7	0	10553	0	6393
	Kathmandu, Nepal	27.7	85.3	1304.8	0	7936	0	6487
	Macau, China	22.2	113.5	40.5	0	12195	0	8977
Cwb	Johannesburg, South Africa	-26.2	28	1755	0	13158	0	12710
	Mexico City, Mexico	19.4	-99.1	2230	0	11867	0	10299
	Harare, Zimbabwe	-17.8	31	1488	0	11673	0	11824
Dfa	Chicago, USA	41.9	-87.6	181.3	2775	0	4946	0
	Minneapolis, USA	45	-93.3	254.8	3119	0	4996	0
	Orenburg, Russia	51.8	55.1	112	8197	0	7042	0
Dfb	Arkhangelsk, Russia	64.5	40.6	1	9137	0	8019	0
	Kyiv, Ukraine	50.5	30.5	157	6296	0	7492	0
	Oslo, Norway	59.9	10.8	5.3	5302	0	5247	0
Dfc	Tromso, Norway	69.7	18.9	10	7191	0	7473	0
	Helsinki, Finland	60.2	24.9	7	7397	0	7540	0
	Bratsk, Russia	56.3	101.8	416	9765	0	9337	0

The Am zone is tropical monsoonal. All cities demonstrated the same pattern. Three cities demand no heating energy and a substantial number of cooling energy. By implementing the Trombe wall structure instead of the wall-oriented South, the cooling energy consumption decreases substantially in Douala from 21255 kWh to 15935 kWh. The same cannot be notified regarding Mumbai city, where the cooling energy demand increased by roughly 800 kWh with the installed Trombe wall. The decrease in cooling demand for Cairns accounted for 20%.

The Aw zone is a tropical winter dry climate area. The annual average solar radiance intensity is higher in Caracas than in other cities, which demonstrates the vulnerability of energy-building performance to changes in the HVAC system (Yang, Li, and Hu, 2006). The same behavior could be noticed, as in Am zone, no heating energy consumption is needed in these cities. However, a bit different results were obtained. For instance, the cooling demand of Brasilia and Caracas almost did not change and was approximately left at that level. Whereas the cooling energy consumption of the building in Havana increased by roughly 5000 kWh with the installation of the Trombe wall.

The BSh zone is arid steppe hot arid. The implementation of the Trombe wall positively reflected the cooling demand parameter. The cooling energy consumption decreased in all three cities of the BSh zone. The least decrease counted for 14 kWh, while the highest number exceeded 2000 kWh. For instance, the change in cooling demand in New Delhi is equal to 2116 kWh. In addition, the least difference was registered in Tripoli and it counted for 14 kWh.

The BSk zone is arid steppe cold arid. The buildings in Karaganda city demonstrated a need for heating energy and the installation of the Trombe wall enabled the fall in heating energy demand in buildings. The decrease in heating energy demand is found to be approximately 1500 kWh. The buildings in Tehran and Valencia showed insignificance in heating energy and the need for cooling energy in the living space. However, the BSk climate zone's results are controversial with the BSh climate zone's values. To be more precise, the cooling demand of Tehran and Valencia increased by roughly 50-100% in comparison with the building envelope without the Trombe wall.

The BWh zone is an arid desert hot arid. It can be seen that the higher value of solar radiation belongs to Doha, which results in a much higher cooling energy load required to maintain comfortable conditions in a building (Yang, Li, and Hu, 2006). These cities are located in the desert area; therefore, the heating energy is non-preferrable and accounts for 0 kWh and all three cities. However, all these cities demand a lot of cooling energy. For example, the implementation of the Trombe structure into the building in Abu Dhabi and Doha cities would increase the demand for cooling energy. The opposite behavior is noticed in Cairo. The cooling energy consumption would decrease substantially with the installation of Trombe wall architecture instead of one wall.

The Cfa zone is a temperate fully humid climate with hot summer. The highest solar radiation intensity in Atlanta justifies the higher energy consumption of a building (Yang, Li, and Hu, 2006). The cities of temperate and fully humid climate zoning demand heating energy of at least 3032 kWh and a maximum of 5512 kWh. It seems to be apparent that with the installation of the Trombe wall structure, the building envelope in Atlanta neglects the usage of heating energy and parallelly the demand for cooling energy decreased in the city. The heating need in Belgrade and Bucharest has a fluctuating behavior. For instance, in Belgrade, the energy demand decreased by only 237 kWh, and in Bucharest, the demand increased by 413 kWh.

The Cfb zone is a temperate fully humid climate with warm summer. The Installation of the Trombe wall had a diverse effect on the energy demand of building envelopes in different cities. In Amsterdam, the heating demand increased by almost 400 kWh, while no cooling demand occurred. In Bilbao, vice versa no heating demand was denoted, however, the increase in cooling energy consumption was considerable and the value increased by roughly 300%. The building in Brussels demonstrated stability with a little decrease in heating demand.

The Csa zone is temperate summer dry and hot summer zone. It seems to be apparent that the solar radiance values are higher in Algiers, which consequently implies more energy demand (Yang, Li, and Hu, 2006). The cooling energy consumption of the building in Algiers was decreased in comparison to the building structure without the Trombe wall. The decrease accounted for 18%. In other cities, Barcelona and Athens, the installation of the Trombe wall had adversely affected energy consumption, specifically, it increased. For instance, in Athens, the cooling energy demand for building with Trombe walls is almost four times of demand for buildings without Trombe wall structures. In Barcelona, the heating demand also increased but only by more than 150%, from 301 to 770 kWh.

The Csb zone is a temperate summer dry and warm summer climate. From the simulation results, it is seen that the installation of the Trombe wall structure negatively affected the energy demand for building envelopes in the Csb region, as the demand increased substantially. For example, if the cooling demand in Cape Town and Vancouver went upward by 1000 kWh, the cooling demand in Cannes increased to 4500 kWh. The reason could be the composition of wall and roof structures.

The Cwa zone is temperate winter dry and hot summer climate area. The implementation of the Trombe wall structure positively reflected the cooling demand parameter in all three selected cities. The cooling energy demand in building envelope located in Hanoi city dwindled by almost 50%, particularly from 10553 kWh to 6393 kWh. The same pattern was denoted in Macau, where the cooling consumption decreased from 12195 kWh to 8977 kWh. The cooling energy load in a building with an installed Trombe wall structure diminished by almost 20% in Kathmandu, Nepal.

The Cwb zone is temperate winter dry and warm summer climate area. The heating energy demand was negligible for selected cities in the Cwb climate zone. The installation of the Trombe wall structure did not change considerably the energy load in cities. A small increase in cooling energy demand was detected in Harare, where the demand changed from 11673 kWh to 11824 kWh. The minimum decrease in cooling energy consumption is identified in Johannesburg (South Africa). More precisely, the demand decreased by approximately 4% in comparison to the results taken from the basic building envelope.

The Dfa zone is cold fully humid and hot summer climate classification. The cities are mainly located in cold areas, which results in high heating energy demand values, and simultaneously the cooling energy load is neglected. The installation of the Trombe wall system decreased the heating energy demand in Chicago and Minneapolis cities. To be more specific, the heating demand in Chicago increased from 2775 kWh to 4946 kWh with the embedment of the Trombe wall, and the demand for building envelope located in Minneapolis changed by roughly 1800 kWh.

The Dfb zone is a cold fully humid and warm summer climate classification. Three cities selected from this climate zone are Arkhangelsk (Russian Federation), Kyiv (Ukraine), and Oslo (Norway). It is apparent fact that the cities located in cold climate regions demand more heating energy rather than cooling energy values. Two cities, particularly Arkhangelsk and Oslo, demonstrate the positive effect of installing the Trombe wall structure into a building envelope by decreasing the heating energy load. To be more precise, the positive change in the Arkhangelsk building envelope's demand accounted for 1118 kWh, and in Oslo only 55 kWh. Whereas the heating consumption increased in Kyiv by approximately 1200 kWh.

The Dfc zone is cold fully humid and cool summer climate classification. The heating energy demand in all three selected cities dwindled with the installation of the Trombe wall structure. The overall decrease was approximately equal to 5% of the energy demand of the basic building envelope. For example, in Bratsk, the heating load decreased from 9765 kWh to 9337 kWh with the installation of the Trombe wall.

4. Conclusions

The research paper observed the efficiency of installing the Trombe wall into the building envelope. It was done by energy simulations in DesignBuilder software and then the extracted energy demand data were compared with each other. The results show that the Trombe wall efficiency in declining the overall annual energy demand in buildings is not high in particular climate conditions. For instance, in the Cwa climate area, which characterizes by dry winter and hot summer, the building with embedded Trombe wall structure decreased the cooling demand in all three selected cities (Hanoi, Kathmandu, Hanoi). The energy load results of building with a Trombe wall in the BSh climate zone also dwindle in comparison with the basic building envelope. However, in other climate conditions, either all or some parameters were increased with the installation of the Trombe wall. Such deviated results could take place due to the inappropriateness of chosen wall and structural elements' compositions. For future studies, it is suggested to select one zone, figure out the relevant wall and roof composition and find out the most fitting parameters to maximally reduce the heating and cooling demand of the building envelope.

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Development of Resilient Safety Culture Model Using Qualitative Data Analysis

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Abstract

Resilient engineering is a new area of research in safety engineering. Resilience is required in modern, dynamic organizational environments to more comprehensively address safety issues. The resilient safety culture of an organization can be attributed to behavioral, psychological and managerial capabilities as found in literature. To explore the concept of resilient safety culture in the extant literature, Leximancer (an automated text mining tool) was used to analyze 117 articles on safety culture including papers which dominate the resilient safety culture domain to a) assess the existence of several constructs and b) how they are conceptualized. There were two methodologies involved, one looking through focused approach and other using holistic approach. The analysis revealed that there were four major themes: resilience, managerial, psychological and behavioral. These themes were discussed in relation to the current conception of safety culture in the literature and how the integration of resilience can further enhance an organization's safety culture. This paper thus looks at the main themes dominant in the literature and validates the literature review which was done to develop the resilient safety culture model.

Keywords

Data mining, resilient safety culture, themes, concepts, literature review

1. Introduction

Resilient safety culture is a new concept which has been proposed in order to address the weaknesses of safety culture. It is a safety culture with resilience, aims to learn, and seek out continuous improvements and cost effectiveness measures [1]. Resilience Engineering (RE) is added in the safety culture to look at safety in a different way and is sometimes referred to as safety-II way. This safety-II way was proposed since the current safety-I had drawbacks as the fatalities have not been fully reduced and the researchers were looking at the dynamic aspect to figure out if this methodology can be of assistance. This methodology is not an alternative to safety-I but is in addition to safety-1 concepts. RE looks at learning as an important way to take care of dynamic challenges thus safety-I and safety-II both are incorporated in the RE. The leading and lagging indicators both give additional information to the model to stay abreast in the changing environmental scenarios.

This study understands the various predominant themes prevelant in the literatuture which develops the resilient safety culture model and thus validates the model using the automated text mining tool, Leximancer. The following sections will discuss resilience engineering and how it is incorporated into an organisational safety culture. This is followed by a discussion of the methodology and how leximancer was employed using thematic and conceptualise analysis to uncover themes and concepts.

In terms of qualitative analysis, Leximancer was used in this study. There have been multiple softwares available in the market which can be used for data mining. Nvivo and Leximancer are the two main which stands out. NVivo has been the leading software but Leximancer has grown in popularity [2]. The main difference between these two softwares is that Leximancer provides a form of automated analysis based on properties of texts, NVivo requires manual handling of data which is not very beneficial in large qualitative data analysis and is subject to greater levels of subjectivity in coding and analysing texts. Leximancer uses bayesian statistics to analyze texts and visually display the information to form concept maps and network clouds [2]. Leximancer has notable advantages such as quantify concepts, split and then analyze documents and generate its own dictionary. It also has the characteristic to identify word frequencies and relationships between concepts in terms of under-root foundation then displays the information in interactive visualized map form [3].

Previous studies have used Leximancer in various areas studied how to solve grievenaces in terms of procedures, roles of individuals and outcome in line with policy through Leximancer [3]. Leximancer helped look underlying themes and concepts that may be missed or overlooked by other analysis. Harwood investigated the potential of Leximancer to support the Grounded theory (GT) analyst in assesing the completeness of his study. It was found that Leximancer output showed smilarities to the main themes emerging from the GT analysis. It was concluded that Leximancer can provide a useful, effcient and impartial crosscheck of saturation in the open coding stages of the GT study. Tseng et al. used Leximancer to identify nine major textual themes and their relationships among these themes [4]. Further the paper looks at the various topics which define the dominant themes which are used to develop the resilient safety culture model and how the papers in the literature were selected.

1.1 Safety

Safety is defined as the absence of accidents where accident is an event which lead to unacceptable loss [5]. Safety is a system property and not component level property. In the past, the product designs were manageable as the components interactions were understood properly but now it is getting hard due to complexity in the system. This complexity has introduced new challenges. Since, there is no full control over the socio-technical system, complexity is not taken into consideration when designing the safety systems [6]. Previously, most systems employed conventional risk management techniques to deal with risks which were based on knowledge of previous experiences, failure reporting and risk assessments by computing historic data. But today, these are traced to organizational factors, functional performance variability and unexpected outcomes [1].

There has been an evolution from past theories in safety management which contributed to the knowledge. Each stage was not left behind but was built upon which was already there. There have been five eras of safety management. First is the technological era, second is the behavioral and human factors, third is the socio-technical era, fourth is the cultural and fifth and latest is the resilience engineering era [7]. There are various research papers which emphasize the causal link between risk and variability as a starting point of resilience. Primary risk areas is personal risks, risks due to errors committed , risks due to insidious accumulation of latent conditions within the maintenance, managerial or organizational spheres, risk due to third parties [8]. Why resilience is used in the safety theory is discussed in the following topic.

1.2. Organizational resilience

Resilience in the system is what is required to bounce back from any strain in the system [9]. Resilience is sometimes called resilience engineering or RE. Resilience engineering is recognized as other alternative to traditional approaches in safety management. One of the definitions of resilience engineering is "*intrinsic ability of a system to adapt its function before or after the mishaps so it can continue to work under both expected and unexpected conditions"* [10]. The challenge for health and safety is to draw up prevention strategies which adequately address complex, dynamic and unstable systems [11]. The idea behind resilience engineering is that an organization must continually manage risks and create an anticipating, monitoring, responding and learning culture. Pillay et al. identified three dimensions of organizational resilience: cognitive, behavioral and contextual. Figure 1 shows the structure of organizational resilience.

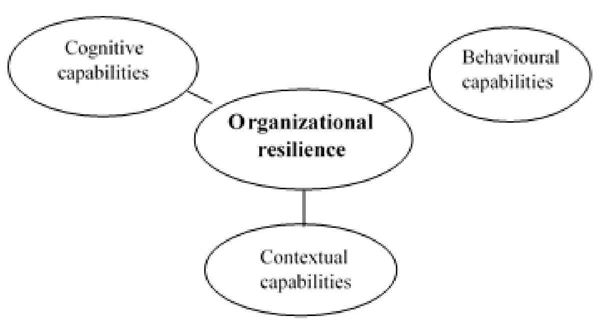

Fig. 1. Organizational resilience structure

Cognitive or psychological capabilities notice and interprets uncertain situations, analyses and formulate responses. Organizations with cognitive capabilities encourage ingenuity and develop new skills. Behavioral capabilities move the organization forward that means it enables a firm to learn about the situation and fully utilize its resources. Firm having choices of different actions it can take and easily adopt to market shifts in unexpected situations. Contextual or managerial capabilities provide the setting for integrating cognitive and behavioral capabilities. It consists of connections and resources. This organizational resilience influences an organizational response to environmental change. It encourages the firm to develop varied repertoire of routines for responding to uncertainty and complexity in the system. It also encourages the firm to think about its environment such that it can improve its ability to determine the content and duration of change [12]. Let's understand what safety culture is and its subcultures to better understand why resilience engineering is important and why resilient safety culture is used and modelled.

1.3 Safety culture and sub-cultures

Safety culture is branched out of organizational culture [13]. Organizational culture is considered to be "top-management business". A term used as observed in behavioral regularities when people interact, formal philosophy, rules of the game, organizational climate, embedded skills, habits of thinking paradigms [14]. Many studies have been done on safety culture, but it has been seen that safety culture is not fully understood. Safety culture is divided into many sub-cultures as seen in figure 2. It shows the safety culture with other cultures in inter and intra-relationships [8]. This can be due to focusing only on "just culture" and disregarding resilience aspect. The main drawback is the dynamic aspect of the culture is not taken into consideration interaction between people, technology and administration [1].

Safety management, safety climate and safety culture are terms which are used interchangeably but they are all different. Safety climate is dependent on safety culture [14]. Safety management is documented and formalized system of controlling against risk, but the actual safety management system cannot reflect actual practice. That is where the term safety culture is used. It is the safety culture that influences the deployment of safety management resources, procedures which represent the actual work environment.

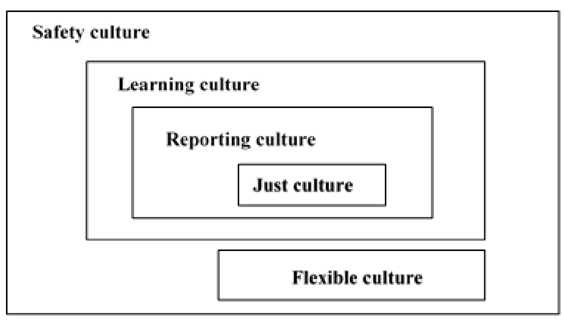

Fig. 2. Safety culture and its relationship with other culture types [8]

Learning culture is the degree to which an organization responds to problems with denial versus modification [10]. It involves organizational learning, organizational memory, learning from accidents and disturbances, observations, investigations, risk analysis and research [15]. Reporting culture is a subset of learning culture since learning is limited without good reporting. Reporting culture is cultivating an atmosphere where employees have confidence to report safety-related issues without fear of blame. Reporting culture brings about a just culture, which is motivation for reporting, user-friendly forms of reporting, good training, feedback from reports, and regular follow-up by management [15]. Just culture is an atmosphere of trust that workers are encouraged to report essential safety concerns and issues but also gross negligence, willful violations, and destructive acts which are not tolerated. Flexible culture involves shifting from bureaucratic mode to a mode where knowledge, skills and abilities counts which leads the task in challenging situations and shifting back again when the challenges are gone [16].

Safety culture is also defined as having three aspects: psychological aspect, which is about safety climate and how people feel, behavioral aspect which is what people feel and situational aspect talks about safety management system and what organization has as a structure [16]. The situational aspect deals with the structure of the organization, its policies, procedures, management systems. The behavioral aspect is measured through peer observations, self-reporting and outcome measures. The psychological aspect is critical and is measured by safety climate questionnaires to understand the employees' perception of safety. Some authors infer that psychological/cognitive capabilities come under just culture, behavioral capabilities come under reporting culture, managerial/ contextual/ situational capabilities come under flexible and learning cultures [8], [17]. The main drawback in safety culture is the dynamic aspect of the culture is not taken into consideration in the interactions between people, technology and administration [1]. That is why there is need for a resilient safety culture model.

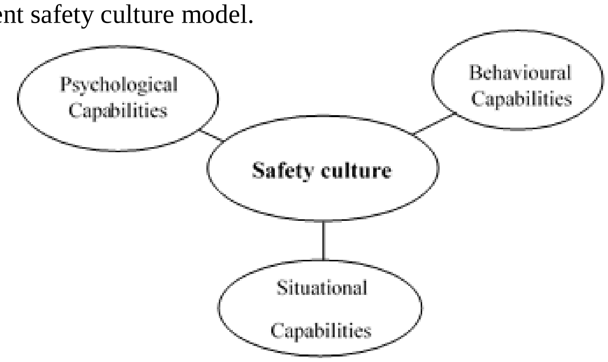

Fig. 3. Safety culture structure as perceived by many authors

Understanding figure 2 and figure 3, it has been explained by some authors that psychological/ cognitive capabilities come under just culture, behavioral capabilities come under reporting culture, managerial/ contextual/ situational capabilities come under flexible and learning culture [8], [17].

The safety, safety culture and organizational resilience are the three main domains under which the resilient safety culture model is located. This is the basis for the literature review for this study. Further the Leximancer is used to pinpoint the themes and concepts which help in generating the resilient safety culture model.

2. Research Methodology

Leximancer allows research to conduct automated thematic and conceptual analysis of text based data, in this case, journal articles. The texts are partitioned into user-defined coding segments and then using baysian statistics. Leximancer analyzes the occurreance and co-occurrence of word pairs within the coding segments to uncover not only the concepts and themes within a piece of text (or texts) but to also find the connections between them [3]. Leximancer builds concept families aound words which it then uses to code or classify each sentence or two sentences block with the presence of multiple concepts. Leximancer has several advantages over traditional coding methods namely that it is automated, reducing the likelihood of human bias, and can analyse large masses of data [3]. With 117 papers being used in this study, Leximancer was a logical choice. Whilst this study is using Leximancer to triangulate and verify the established model, it has been used in contexts such as the improvisation in safety critical situations using Leximancer by Trotter [18], and Colquhoun et al. studying the link between indigenous culture and wellbeing [19].

Figure 4 shows the flow chart how Leximancer creates automatic map of the documents. Text preprocessing is the first phase of the processing. This phase converts raw documents into a useful format for processing. In the automatic seed extraction, the important concepts are automatically identified from the text. In the concept editing phase , the users have the option of deleting automatically identified concepts that are not of interest, adding extra concepts or merging concepts. Concepts in Leximancer are collection of words that travel together throughout the text. For example,"rifle" may have other terms such as "ammunition" or "bullet". The learning phase identifies such clusters of words that surround the main term. Once the concept definitions have been learnt, each block of text is tagged with the names of the concepts that it contains. This process is similar to manual coding. The last phase of processing is "mapping" in which the conceptual map that displays the relationship between variables is constructed [20].

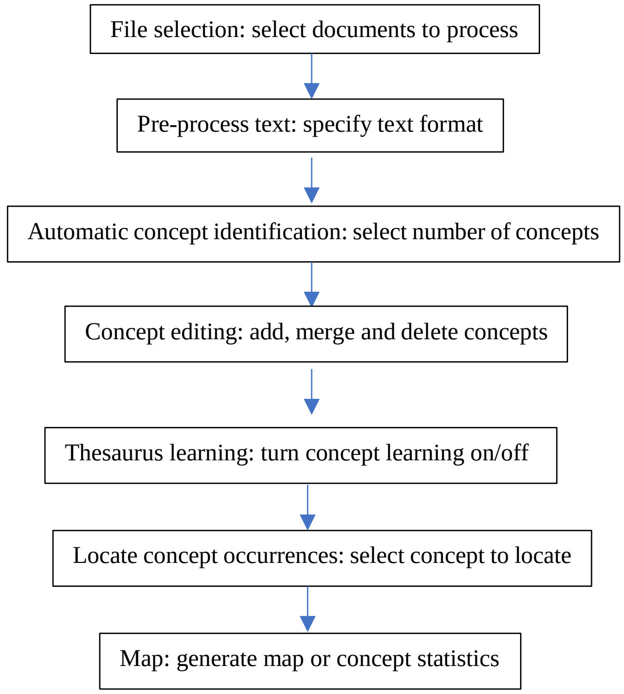

Fig. 4. Phases of processing in Leximancer [20]

In this study, the goal of using Leximancer is to generate themes and concepts which help in building the resilient safety culture model. We find journal articles which relate to safety culture (SC), resilience (R), psychological capability(P), behavioural capability (B) and managerial capability (M). Six electronic databases (CINAHL, Google Scholar, PsycINFO, PubMed, Scopus, and Social Science Journals) were searched using "resilience engineering" and "safety culture" as the keyword—i.e., TITLE-ABS-KEY ("resilience engineering," or "safety culture"), to identify articles published or in press from January 1976 to December 2019. The search was limited to full-text articles and conference proceedings published in English. "Grey literature" was also searched by reviewing reference lists to identify any articles that may have been missed. The search of six databases and grey literature generated 3748 articles, from which 3631 duplicates were removed, leaving 117 articles for title and abstract screening. These 117 articles were used for holistic study. A further 78 were screened out at this stage, resulting in 75 articles for full-text review. An additional 58 were deemed not eligible at this stage due to repetition, resulting in 17 studies for the final review and synthesis. These 17 articles were used for the focused approach. The study collected journal articles which relate to safety culture (SC), resilience (R), psychological capability(P), behavioural capability (B) and managerial capability (M). The appendix gives the whole list of these papers. The authors segergated the search to two types-focussed and holistic approach , one was the 17 focussed papers which they felt would extract enough information which they were looking for and the other was the total set of all the papers which had the 117 papers included along with other relevant papers. The 117 papers had broad list of papers which touched on the B, M, SC and P topics

2.1 Method

The settings for the 17 focused papers were as follows. In the text processing options, the authors choose one sentence per block, selected break at paragraph, selected merge word variants. In concept seeds identification, the authors selected automatically identify concepts. Automatic concept identification is the phase of processing in which seed words are identified as the potential starting points of concepts. In concept learning, selected learn concepts thesauras using source documents. In classification settings, selected behaviour, management, pshychological and resilience as required concepts. Rest remaining settings were default settings.

The settings for the 117 papers project was as follows. In the text processing settings, sentences per block was one, merge word variants were selected along with break at paragraph. In concept seeds identification, selected automatically identify concepts. In concept learning, selected the learn concept thesaurus using source documents. Required concepts in classification settings were behaviour, management, psychological and resilience.

Both the settings, focussed and holistic choose social maps in the concept mapping out of the social and topical maps. Social maps has more circular symmetry and empahisze the simmilarity between the conceptual context and the words appear. This type of map is best when entities tend to be related to fewer other entities. The topical map is more spread out which empasize the co-occurence between items. It is best for discriminant analysis. The topical map is more stable for highly connected entities such as topics. Topical clustering algorithm is more stable but will discover fewer indirect relationships. The cluster map should be considered as indicative and should be used for generating hypothesis for confirmation in the text data [20].

These settings were generated to focus on four themes only which is resilience, behavioural, managerial and psychological and how these four themes interact with each other and what concepts it generates using the focused and holistic approach. The goal of Leximancer was to identify which set of papers to follow and which themes were generated using both these approaches and also once the set of papers were identified from the two approaches, the resilient safety culture model was developed using those papers.

3. Results

3.1 Focussed approach

Top four themes using the focussed as well as holistic approach are resilience, psychological, behavioural and managerial as configured for Leximancer to generate. The concept maps generated themes other than these four themes, then the inter-relationship between these themes cannot be understood. Figure 5 shows the amount of hits of these themes get using the 17 papers. The amount of hits are less as compared to holistic approach since the number of papers were less comparativily as seen in figure 8. Maximum hits were for resilience with 686 hits followed by management, behaviour and psychological. Figure 6 shows the top emergent concepts with “resilience” and “capacity” are the most relevant. It shows that the resilience tops and subsequently behaviour, management and psychological are subsets.

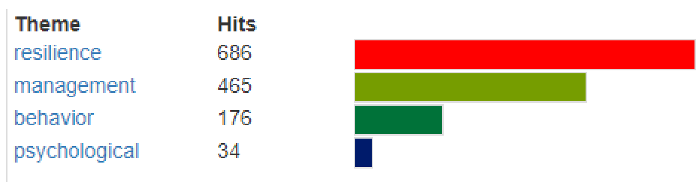

Fig. 5. Top level hits for 17 focussed papares (Leximancer)

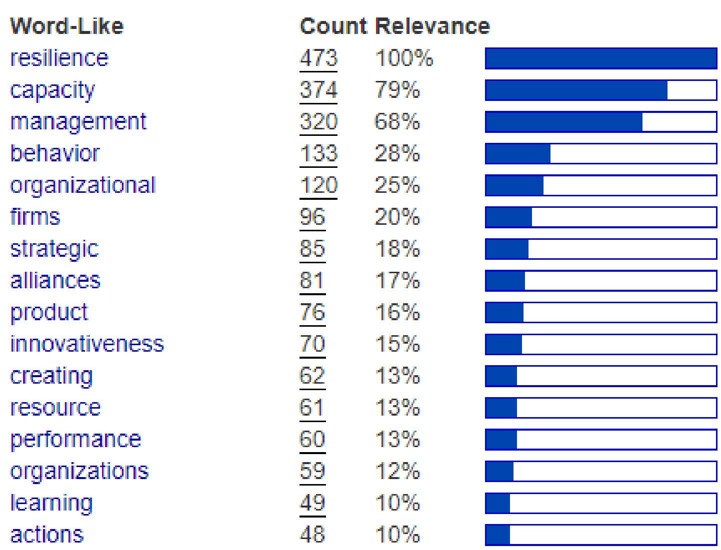

Fig. 6. Top ten words with relevance for the 17 focussed papers (Leximancer)

Figure 7 shows the themes and concepts using 17 focussed papers choosen. The top concepts come under “resilience” theme. It should be noted that behavior incorporates large amount of space in the map. The behavioural capability does play a very important part in the RSC model. It is human resource development attribute which the organization need to focus since it is very complex capability and it gets influenced by the psychological and managerial capability together.

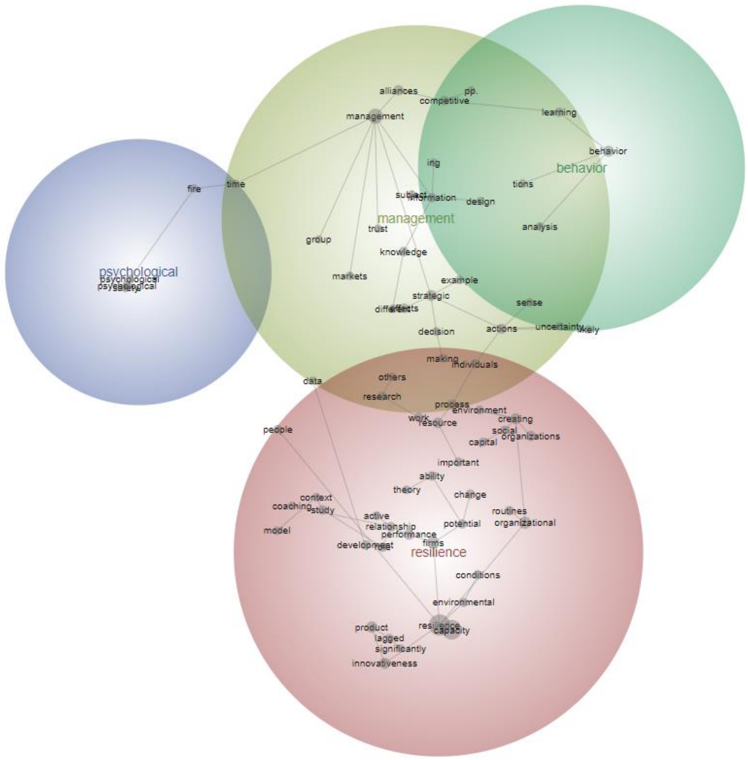

Fig. 7. Leximancer created themes using 17 focussed papers

3.2 Holistic approach

Figure 8 shows the top four themes including resilience, managerial, behavioral and psychological. Management with highest hits of 2828, resilience is second with total hits of 2611, third is behavior with hits of 1121 and psychological with 192 hits. Holistic approach is further chosen for our study for the results since it gives bigger hits on relevant themes and has more data to work with. It also shows better results to generate the resilient safety culture model. The themes in the Leximancer concept map are heat mapped that means the hot colors which are red, and orange denote the most important themes then comes the cool colored blue and green which shows less important themes.

Figure 9 shows the top ten most prevalent concepts including “management”, “resilience”, and “behavior” with first, second and third. Concepts come under themes. Management which is top in the list of concepts which shows that this concept is most prevalent. The relevance is just a percentage frequency of text segments which are coded with that concept, relative to the frequency of the most frequent concept in the list. The most frequent concept will be 100% always. This does not mean that all the text segments contain that concept.

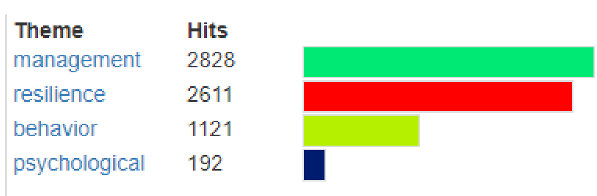

Fig. 8. Top level theme hits for 117 papares (Leximancer)

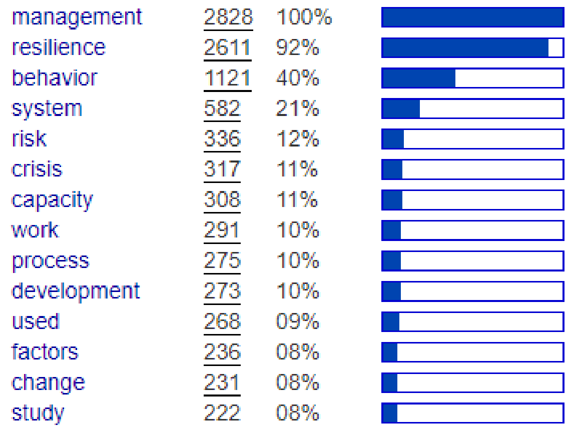

Fig. 9. Top ten words with relevance for the 117 papers (Leximancer)

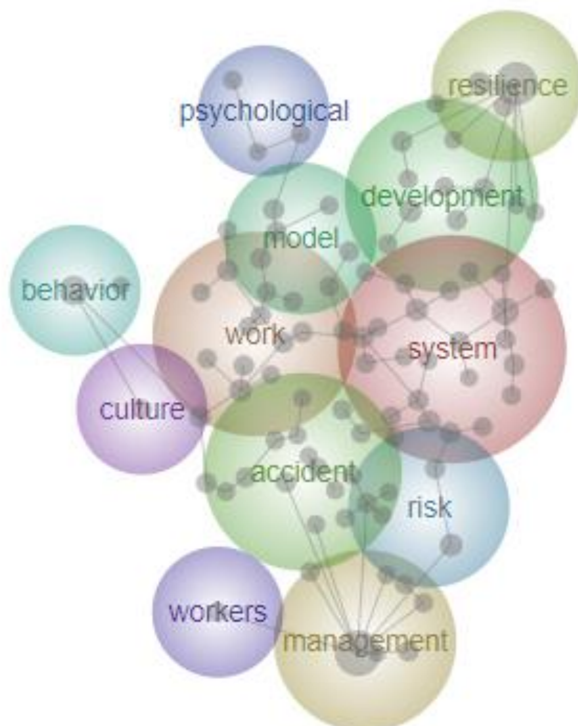

Fig. 10. Leximancer created lower order themes using 117 papers (holistic approach)

Figure 10 and 11 shows holistic approach based themes and concepts. This shows more information and more saturation using large database. The themes are constrained to just four in figure 11 using higher order themes (theme size) but it shows more concepts and interconectivity. The resilience has the highest theme followed by managerial capability then behavioral and then psychological capability. It should be noted that as discussed further in the discussion section, psychological capability is the least focussed theme in the literature survey which should not be the case since the psychological capability is the foremost capability which the management or organization need to focus on before going to behavioral and managerial. Lot of papers on managerial capability shows high priorities given in the industry in this area and also in the related studies as well. Leximancer can easily see where the focus is while using the literature survey.

A leximancer theme is a group or cluster of concepts that have some commonality or connectness. The size of the theme has no bearing as to its prevelance or importance, the circles are merely the boundaries. Looking at the managerial capability theme, we find that “management”, “crises”, “risk”, “problems”, “workers”, “policy”, “information”,”procedures” are various concepts which are prevelant to this theme. This is the theme which the literature talks about in the system in place where the HRM works and controls.

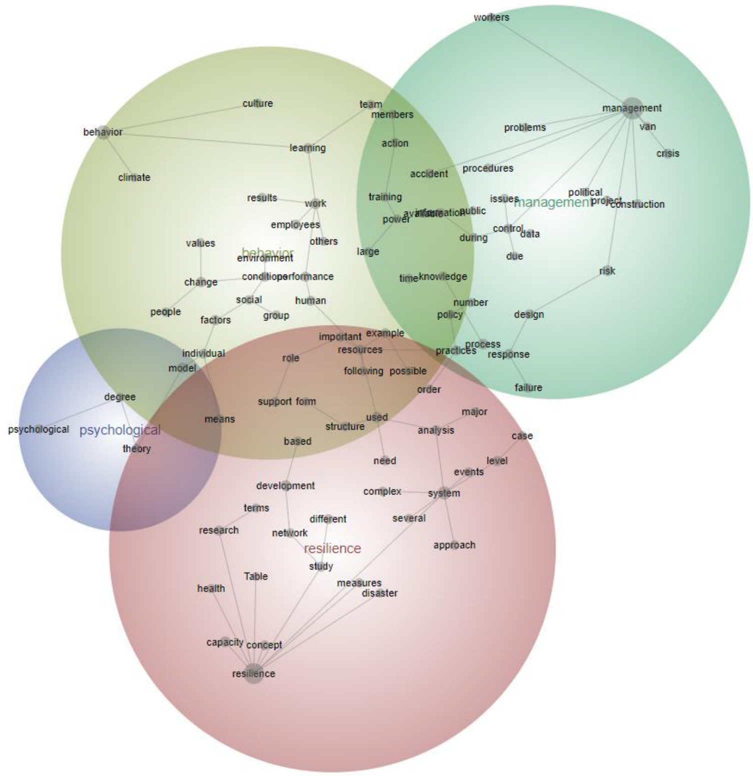

Fig. 11. Leximancer created higher order themes using 117 papers (holistic approach)

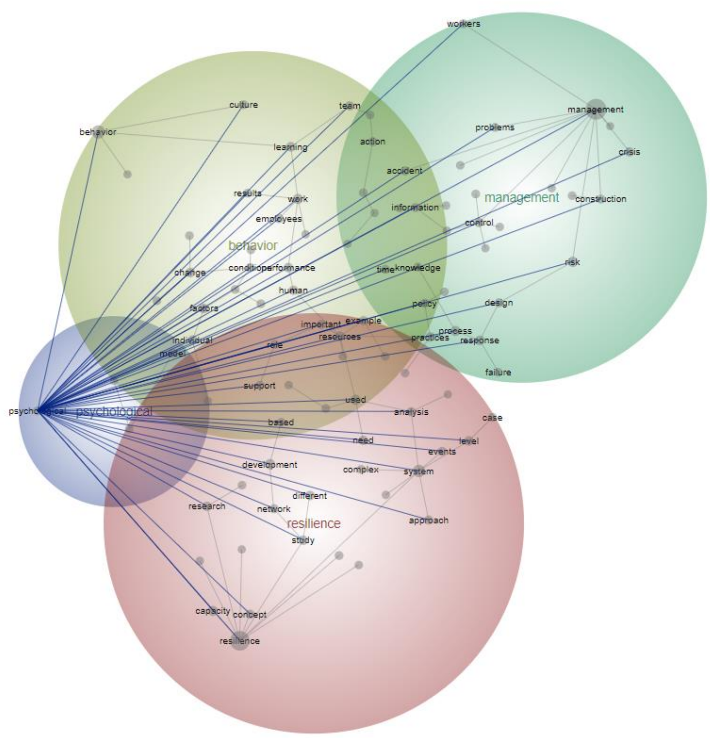

Fig. 12. Psychological concept interconnectedness

Figure 12 shows the Psychological concept interconnectedness with the other concepts in other themes. Similarly, other concepts can easily be seen how they are connected in the concept map. Appendix 1 shows the various references which were used to generate these concepts and themes for comparison with the RSC model. This table shows which papers focuses on which area and how all the areas are covered. A comprehensive literature review was done to generate the Leximancer results along with the RSC model.

4.0 Discussion and Conclusions

4.1 Resilient safety culture model

Figure 13 is the model generated seeing how resilience, psychological (cognitive), behavioral and managerial (contextual) capabilities are interlinked. As seen from the figure 11, the resilience is present in all the themes and thus the management, behavior and psychological thus form the sub construct to our model. It shows how the total holistic view of the whole scenario where the resilience engineering plays its part. The uncertainty influenced on the system is taken care by resilience characteristics of the system which enhances the system performance as given in literature. Seeing figure 11, the resilience relates to the psychological, behavioral and managerial themes and "system" and "performance" are the concepts in concept map.

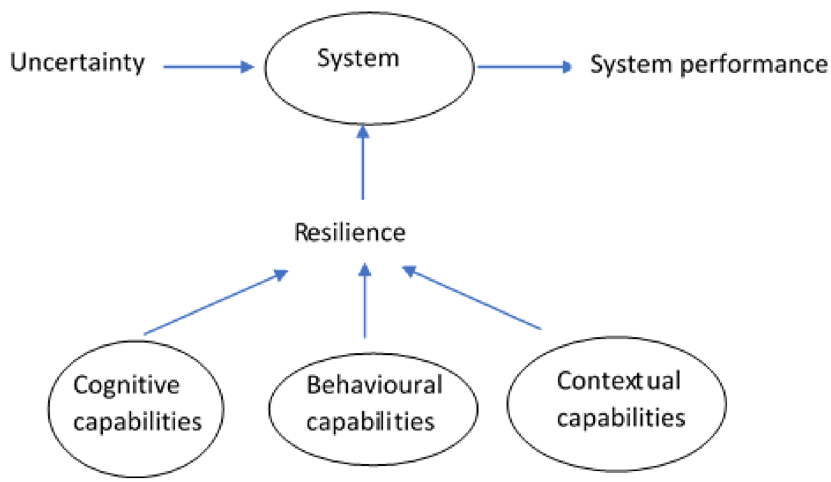

Fig. 13. Resilient safety culture model

The psychological/cognitive capabilities of an organization enable an organization to notice shifts, interpret unfamiliar situations, analyze options and figure out how to respond. It relates to sustaining pressures in a company environment and is a personality trait. Behavioral capabilities comprise of established behaviors and routines that enable an organization to learn more about the situation, implement new routines and fully use its resources. Managerial / contextual capabilities is combination of interpersonal connections, resource stocks and supply lines that provide a foundation of quick actions [21].

Following sections will look in to psychological, behavioral and managerial capabilities in more details as found in the literature to understand the concept and thus explain the resilient safety culture model.

4.1.1 Psychological capabilities

Psychological/cognitive capabilities of organizational resilience is based on constructive sense making and conceptual orientation [12], [22]. Organizations can foster a positive, constructive conceptual orientation through a strong sense of purpose, core value, a genuine vision and a deliberate use of language [23], [24]. Strong core values coupled with sense of purpose and identity encourage an organization to frame conditions in ways that enable problem solving and action rather than in ways that lead to either threat rigidity or dysfunctional escalation of commitment [25], [26].

Constructive sense making enables firms and employees to interpret and provide meaning to unprecedented events. Collective sense making relies on the language of organization to construct meaning, describe situations and imply both understanding and emotion. It requires an attitude that balances the contradictory forces of confidence and expertise against skepticism, caution and search for new information. Each situation is unique and contains features that may be subtle but that can be powerful in shaping consequences, relations and actions [19]-[21]. The mindset that enables a firm to move forward is one that consists of expertise, opportunism, creativity and decisiveness despite uncertainty. Cognitive foundations require a strong knowledge on reality and desire to question fundamental assumptions. The ability to conceptualize solutions which are novel and appropriate is desired [21].

4.1.2 Behavioral capabilities

Behavioral capabilities are based on behavior which helps get rid of any problems they face with their own ability and resources. Learned resourcefulness, ingenuity and bricolage are all the characteristics which are needed to cope with various challenges [22], [25]. It can be developed using practiced resources fullness and counterintuitive agility along with useful habits and behavioral preparedness [12]. The ability to follow a dramatically different course of action from what is the norm are the behavioral elements of organizational resilience. Behavioral resilience also relies on development of practical habits which are useful which provide first response to an unexpected threat. Organization which develop values that lead to a habit of investigation as compared to assumption, routines of collaboration rather than antagonism and traditions of flexibility rather than rigidity. Behavioral preparedness helps bridge gap between divergent forces of learned resourcefulness and counterintuitive agility and convergent forces of useful habits. It also means organization learns from situations that emerge and unlearns obsolete information. Behavioral preparedness enables an organization to quickly spot an opportunity which others might miss. These organizations translate thoughts into actions [30], [31].

Comparing figure 11 and 7, we find that as we move from the focused approach to holistic approach, the themes tend to merge together closely showing that the themes are more closely related which is needed to generate the original model. The concepts tend to increase since the amount of papers are 117 as compared to the focused approach which generate lot less concepts in the themes. Previous case studies done by authors has found resilience levels reduce predominately because of reduction in behavioral capability. This is related to human resource management of organizations [32] since the psychological and behavioral both come under the HRM category. We can see from figure11 as well that resilience comprises of all the three themes and reduction in any theme can reduce the resilience levels of the organization.

4.1.3 Managerial capabilities

Managerial/contextual capabilities of organizational resilience requires relationships within and outside an organization to facilitate effective responses to environmental complexities. It contains psychological safety, deep social capital, diffuse power and accountability and broad resource networks [12], [22]. Psychological safety is the degree to which people perceive their work is conducive to taking interpersonal risks. When people perceive psychological safety, they are more willing to take these risks. A climate of psychological safety needs to be established for organizational resilience [33]. Deep social capital evolves from respectful interactions within the organizational community. Interactions which are rooted in trust, honesty and self-respect. These interactions build informal intimacy and creates collaborative sense making. It facilitates growth in intellectual capital. Also, it enhances resource exchange. It also eases cross functional collaboration between different kinds of people in an organization. It enhances deep bonds beyond immediate transactions and creates long term partnerships. Finally, it creates network of support and resources [23]-[25].

Diffused power and accountability are another factor associated with creation of managerial resilience. Resilient organizations are not managed by hierarchical structures but by self-organization which create holographic structures where each part is a small replica of the whole organization. Resilient organizations share decision making widely. Each replica has discretion and responsibility for attaining best organizational interests [37], [38]. Broad resource network is the main element in the managerial capabilities of resilient organizations. Resilient individuals have an ability to forge relationships with others likewise resilient firms share relationships with supplier and strategic alliances for sharing resources. Resources gained through the network sharing promotes an assortment of interpretations for alternative applications of these resources. This leads to innovation leading to cultivation of constructive sense making [21], [39].

4.2 Conclusions

In conclusion, a resilient safety culture model was developed. Leximancer showed themes and concepts prevalent in the resilient safety culture model and thus helps in development of the model and provides enough information to understand the relationship between the three capabilities and how much focus currently the literature is focusing on which capabilities. This study is limited to the amount of data available in the literature and thus the Leximancer tool has its constraints due to the constraint in the input data.

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Appendix

Classification of literature based on resilience (R), safety culture (SC), psychological (P), behavioral (B), managerial (M)

#	Reference	R	P	M	B	SC
1	Weick [36]	✓				
2	Thomas et al. [28]		✓	✓		
3	Coutu [25]	✓	✓	✓		

#	Reference	R	P	M	B	SC
4	Freeman et al. [24]	✓				
5	Lengnick-Hall et al. [12]	✓	✓	✓	✓	
6	Lengnick-Hall et al. [21]	✓				
7	Sheremata [40]		✓	✓		
8	Chen et al. [41]			✓		✓
9	Eisenhardt et al. [42]			✓		
10	Miller et al. [31]			✓		
11	Edmondson [33]		✓			
12	Ireland et al. [35]			✓		
13	Mallak [37]	✓	✓	✓	✓	✓
14	Judge et al. [39]			✓		
15	Nahapiet et al. [43]			✓		
16	Akgun et al. [22]	✓	✓	✓	✓	
17	Trinh et al. [44]	✓	✓	✓	✓	✓
18	Cole et al. [45]					✓
19	Shirali et al. [46]	✓				✓
20	Qureshi [47]	✓				✓
21	Kim et al. [48]					✓
22	Wachter et al. [49]			✓		✓
23	Daft et al. [50]			✓		✓
24	You [47]	✓	✓	✓	✓	✓
25	Lengnick-Hall et al. [12]	✓	✓	✓	✓	✓
26	Akgun et al. [22]	✓	✓	✓	✓	✓
27	Kashwani et al. [51]					✓
28	Azeez et al. [52]	✓				✓
29	Leveson [5]	✓				✓
30	Shiali et al. [6]	✓				✓
31	Sardoh [53]	✓	✓	✓	✓	✓
32	Lingard et al. [54]			✓	✓	✓
33	DeJoy [55]			✓	✓	✓
34	Boin [56]	✓		✓		✓
35	Boin et al. [57]	✓	✓	✓	✓	✓
36	Choudhry et al. [14]	✓	✓	✓	✓	✓
37	Costella et al. [58]	✓	✓	✓	✓	✓
38	Cox et al. [59]	✓	✓	✓	✓	✓
39	Dalziell et al. [60]	✓		✓		✓
40	Carvalho [61]	✓		✓		✓
41	Fang et al. [62]	✓	✓	✓	✓	✓
42	Suraji et al. [63]	✓		✓		✓
43	Pettit et al. [64]	✓		✓		✓
44	Hollnagel [65]	✓			✓	

#	Reference	R	P	M	B	SC
45	Cooper et al. [66]	✓	✓	✓	✓	✓
46	Muniz et al. [67]	✓		✓		✓
47	Fletcher et al. [68]	✓	✓			✓
48	Flin [69]	✓	✓			✓
49	Zhou [70]					✓
50	Woods [71]	✓				✓
51	Fruhen et al. [72]		✓	✓	✓	✓
52	Guldenmund [73]		✓	✓	✓	✓
53	Guldenmund [74]		✓	✓	✓	✓
54	Haavik et al. [75]	✓				✓
55	Hornell et al. [76]	✓		✓	✓	✓
56	Hopkins [77]	✓			✓	✓
57	Park et al. [78]	✓		✓		✓
58	Trinh et al. [13]	✓	✓	✓	✓	✓
59	Ulrich [79]				✓	✓
60	Hosseinian et al. [80]				✓	✓
61	Maloney et al. [81]		✓	✓	✓	✓
62	Reason [8]			✓		✓
63	Flin et al. [82]			✓	✓	✓
64	Guldemund [83]		✓	✓		✓
65	Mohamed [84]			✓		✓
66	Sorra [85]			✓		✓
67	Steen [86]	✓	✓	✓	✓	✓
68	Koornneef [87]			✓		✓
69	Ouyang et al. [88]			✓		✓
70	Beuzekom et al. [89]			✓		✓
71	Kozuh et al. [90]			✓	✓	✓
72	Lee et al. [91]	✓	✓	✓	✓	✓
73	Shirali et al. [1]	✓		✓		✓
74	Rae et al. [92]			✓	✓	✓
75	Oxstrand et al. [93]	✓				✓
76	Yazdani et al. [94]	✓				
77	Wiig [95]	✓	✓	✓	✓	✓
78	Akselsson et al. [16]	✓				✓
79	Bhamra et al. [96]	✓				✓
80	Mohamed [97]	✓		✓		✓
81	Hollnagel [98]	✓	✓	✓	✓	✓
82	Zellars et al. [99]	✓	✓	✓	✓	✓
83	Reason et al. [100]					✓
84	Richter et al. [101]					✓
85	Rochlin [102]					✓

#	Reference	R	P	M	B	SC
86	Rubio-Romero et al. [103]	✓		✓		✓
87	Wiegmann et al. [104]					✓
88	Pillay et al. [7]	✓		✓		✓
89	Wiegmann et al. [104]					✓
90	Cox et al. [105]					✓
91	Sorensen [106]					✓
92	Vinodkumar et al. [107]			✓	✓	✓
93	Wilson Jr et al. [108]			✓		✓
94	Liu et al. [109]			✓		✓
95	Geller [110]			✓		✓
96	Scott et al. [111]					✓
97	Smith et al. [112]			✓		✓
98	Bandura [113]			✓	✓	✓
99	Annarelli et al. [114]	✓				✓
100	Klockner [115]	✓				✓
101	Sutcliffe [26]	✓				✓
102	Mitropoulos et al. [116]	✓	✓	✓	✓	✓
103	Williamson et al. [117]		✓	✓	✓	✓
104	Choudhry et al. [14]	✓	✓	✓	✓	✓
105	Williams [118]			✓		
106	Pecillo [119]	✓	✓	✓	✓	✓
107	Clark [120]	✓		✓		✓
108	Cooper [17]	✓	✓	✓	✓	✓
109	Trinh et al. [121]	✓	✓	✓	✓	✓
110	Wood et al. [122]	✓	✓	✓	✓	✓
111	Chen et al. [123]	✓	✓	✓		✓
112	Rabbani et al. [124]	✓		✓		✓
113	Grote [125]	✓		✓		✓
114	Calabro et al. [126]	✓		✓		✓
115	Smith et al. [127]	✓		✓		✓
116	Newaz et al. [128]	✓	✓		✓	✓
117	Zhou et al. [129]	✓	✓	✓	✓	✓

From Heritage BIM to Historic (Digital) Twins: A initial bibliometric analysis of subject coalescence for Architectural Heritage

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Abstract

Digital twins (DT) development and integration into the built environment sector presents an opportunity to explore the potential of fusion of DT Building Information Modelling and Architectural Heritage paradigms to provide a new approach to support the use and management of architectural heritage. This is done by conducting a bibliometric analysis and content analysis by evaluating 10 of the most relevant research articles identified from the Scopus database. This is followed by an analysis through VOSviewer to help visualize the results. The research shows that this area of research is continuously growing, however it revealed that the studies are conducted in isolated clusters with no collaboration between authors.

Keywords

Heritage BIM, Historic Digital Twin, Architectural Heritage, bibliometric analysis, literature review

1. Introduction

Architectural heritage (AH) is increasingly seen as an important part of a country's history and cultural identity (Taher Tolou Del et al., 2020). It is highly valued around the world for its tangible aspects namely; age, authenticity, visual aspect, exclusivity and monumentality (Dewi, 2017). Furthermore, the conservation of heritage buildings is widely acknowledged as critical to the sustainability of the built environment they are considered as limited resources that cannot be replaced if not conserved (Nadkarni & Puthuvayi, 2020). Shan et al. (2022) highlight four methods of conservation of architectural heritage; preservation, reconstruction, rehabilitation and restoration. In the UK, the preservation and restoration of heritage is particularly relevant as there is acute need for housing and limited land available for the creation of new buildings without impinging on protected greenbelt areas. Furthermore, much of the architectural heritage that exists within the UK also classified as existing on 'brownfield land' there is great potential to use these methods of conservation for existing brownfields buildings. There are 21,000 brownfield sites in England alone (Hammond et al., 2021).

In recent years there has been a widespread use of Building Information Modelling (BIM), it has combined both 3D modelling and information management. This has enabled the implementation of Historic/Heritage building information modelling (HBIM) to support historic recording and modelling of historical buildings and built assets (Murphy et al., 2013). As BIM technology and prevailing processes have evolved so methodologies for cultural heritage documentation have begun to adopt BIM (Logothetis, Delinasiou and Stylianidis, 2015). However in previous work, much of the methodologies employed have had a focus on undertaking a survey through the use of laser scanners followed by manual approach (Scan-to-BIM) to construct a 3D model through BIM (Bassier et al., 2016).

The implementation of HBIM has also been deemed to deliver advantages in the operational phase of a historic built asset, as it allows the integration and alignment of data with restoration and conservation guidelines (Oostwegel et al., 2022). Furthermore Oostwegel et al. (2022) highlight the potential to bring the multi-dimensional aspects into BIM into the HBIM paradigm such that the digital data can be used to manage the asset in a more efficient way.

As the efficient and sustainable management of built assets becomes more critical, recent initiatives are beginning to look at how digital technologies and the implementation of digital workflows, including BIM, can unlock the potential of the Digital Twin (DT) for the built environment (Shahzad et al., 2022). This evolution towards the digital twin for built environment presents a great opportunity to better explore and understand the potential of DT in the heritage buildings and provide a wider understanding of how BIM, AH and DT paradigms can coalesce to provide a new approach to support the use and management of architectural heritage.

In order to achieve the above, this paper presents an initial bibliometric review of these three topics including how they intersect at various levels to better understand prevailing research agendas and opportunities for new areas of enquiry.

2. Research Methods

Bibliometric analysis is a method of research that has been used since its first introduction by Pritchard in (1969). It has since replaced the statistical bibliography and has become a scientific technique for conducting scientific research (Khanra et al., 2020). The three steps of the research process conducted for this study are presented in figure 1.

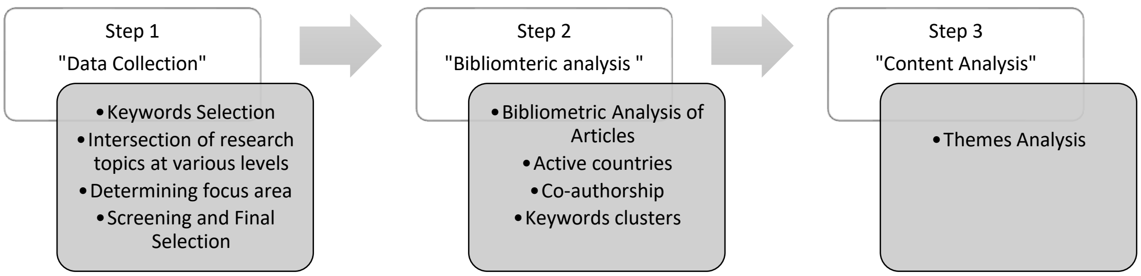

Figure 1- Steps of research process

Step 1: This step aims to collect data related to the intersection of DT, BIM and AH. The initial search was conducted in February 2023 in Scopus as it is among the largest databases of peer reviewed journals. The keywords used for data collection included definitions and keywords related to the study scope. The resulting query is: (TITLE-ABS-KEY (digital AND twin*) AND TITLE-ABS-KEY (bim OR building AND information AND model*) AND TITLE-ABS-KEY (architectur* AND heritage OR built AND heritage)).

Step 2: This step starts with the application of bibliometric techniques to conduct quantitative analysis of the number of papers extracted in step 1. Several data mining software tools are available to conduct scientometric analysis. However for this research VOSviewer was chosen as it is widely available and is suitable for visualising extensive networks of data (van Eck & Waltman, 2013). VOSviewer makes use of the bibliometric data extracted from Scopus search engine to present new perceptions for the research area (Yunwei et al., 2009). The analysis in this section includes the following categories: Countries, authors analysis, authors' keywords, clusters of keywords.

Step 3: This step presents the qualitative analysis identifying knowledge areas and revealing the evolving trends in research related to the intersection of DT, BIM and AH.

3. Results

3. 1 Number of papers and trend of research

This research aims to shed light on an evolving research area that is emerging from the fusion of DT, BIM, and AH. Therefore, a thorough investigation was conducted initially to reveal the number of research papers that focused on each of the specified fields. The search method mentioned in step 1 of the research process was used to find the total number of articles in each area and their intersection at various levels (Figure 2). The results are as follows:

- DT research field: 14,361

- BIM research field: 76,695

- AH research field: 9,162

- DT and BIM fields intersection: 637

- DT and AH fields intersection: 34

- BIM and AH fields intersection: 781

- DT and BIM and AH intersection: 17

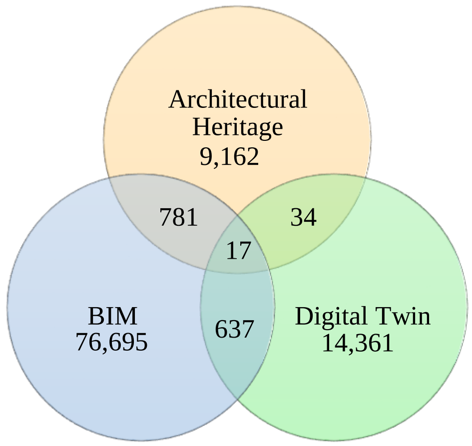

Figure 2- Overall research in each related field

The results enable a clear comparison to identify how the fusion of the three focus areas are investigated in the literature. It is evident that it is discussed in a small number of articles namely 17 in comparison to the individual fields. Due to the limited number of articles the filtering criteria applied was selecting both journal articles and conference papers excluding other types of documents. As a result, only 10 research articles were selected to be exported for further analysis.

The first analysis conducted is publication metric analysis. This is performed to identify the trend in publication rates. The year range for the papers is between 2019-2022 as can be seen in figure 3. Although the overall number of publications is not large, it is evident from the figure that there is a rising trend since the start in 2019, with the highest numbers of publications being in 2022. Nevertheless, the significantly smaller number of publications compared to other areas shown in figure 2 proves the lack of attention paid to this research field.

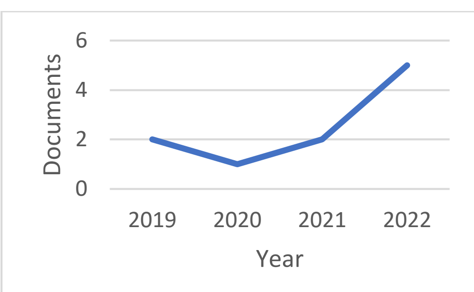

Figure 3- Number of documents per year

3.2 Bibliometrics analysis results

Based on co-authorship analysis, the geographical distribution of the research shows 7 countries are involved in the research field as identified in Table 1. The highest number of published articles came from Italy. This aligns with findings from (Zhang & Zou, 2022) indicating that Italy has the highest number of publications related to heritage BIM research as well. Spain was second with 2 research articles and the remaining regions have 1 research article related to this field. However, Belgium has the largest number of citations (28) which is 42% of the total citations.

The countries that first published around the research topic were United Kingdom and Belgium. Italy has a co-authorship network with Spain and Taiwan and is the latest country to start taking interest in this field of study.

Table 1. The most active countries in the research field

Country	Documents	Citations
Italy	6	15
Spain	2	10
Taiwan	1	0
Belgium	1	28
Brazil	1	6
China	1	3
United Kingdom	1	4

A co-authorship network analysis was conducted in VOSviewer to examine the collaboration of authors, and understand the contribution of each author, this allows a comparison between the number of papers, citations and year of publication. However, figure 4 extracted from VOSviewer shows the network to be fragmented and scattered, revealing a need for more collaboration between authors in the field. This can be due to the novelty of the research topic and lack of research in the field in general. The total number of authors is 37. Jouan & Hallot, (2019) are the earliest researchers who investigated the research topic. They called for a need to strengthen the relationships between the digitalized models of heritage structures and the real-world, to better support preventive conservation of historic buildings. This article suggested the use of DT principles to fulfill that. Bruno et al., (2022) discussed the need to solve criticalities of exchanging data during a restoration project, from the early preliminary stages until the execution and monitoring process. Those authors also indicated that the digital twin capabilities are investigated to overcome this fragmentation in the restoration process (Bruno et al., 2022).

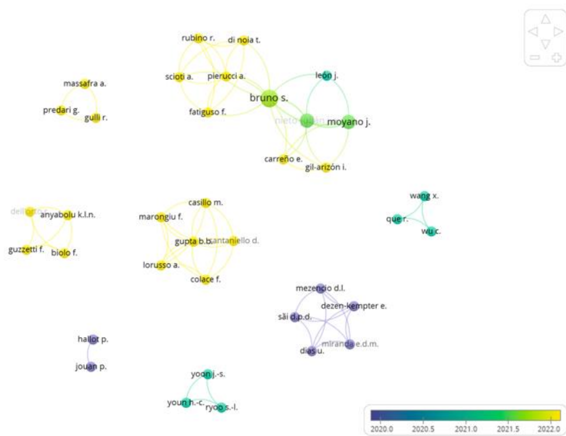

Figure 4- Co-authorship network of the most active authors

The co-occurrence of author keywords analysis was carried out to simplify the visualisation of the most pressing issues in this research area. This aids in identifying the emergent research trends. The analysis is a method to understand the knowledge components and knowledge structure. All keywords were divided according to relative groups of clusters generated by VOSviewer software. The main keywords and their related words from each cluster are shown in table 2. Figure 5 is a visual representation of the themes that have been the focus of investigation in papers related to the fusion of DT, BIM and AH.

Table 2- Keywords clusters as presented in VOSviewer

1- Digital Twin	
Keyword	**Occurrence**

Digital twin	7
Heritage documentation	1
Parametric objects	1
Preventive conservation	1
Restoration project	1
Revit	1

2- Architectural Heritage	
Keyword	**Occurrence**
HBIM	6
Architectural heritage	1
Algorithm rebuild	1
Augmented Reality (AR)	1
Automatic segmentation	1
Conservation and documentation	1
Grasshopper	1
Heritage interpretation	1
Laser scanning and photogrammetry	1
Modern architecture	1
Segmentation algorithm	1

3- BIM	
Keyword	**Occurrence**
BIM	3
Castello sforzesco	1
Deep learning	1
Digitization	1
Historic preservation	1
Information heritage	1
Internet of things	1
Methodological approach	1

4- Building Energy Model	
Keyword	**Occurrence**
Cultural Heritage	2
Building Energy Model	1
Building performance	1
Energy improvement	1
International Foundation Class	1
Material characterization	1
Multi-criteria analysis	1
Non-destructive evaluation	1
Virtual Reality (VR)	1

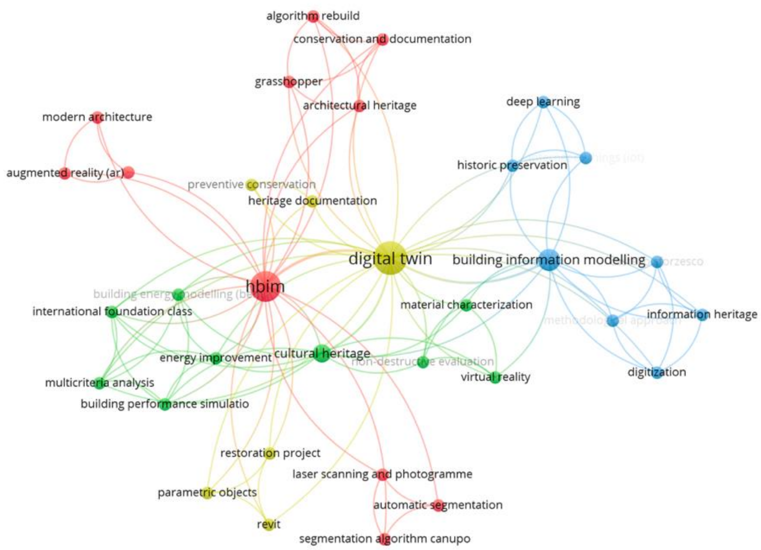

Figure 5- Scientific analysis map of author keywords

3.3 Content analysis

The content analysis results are based on the co-occurrence of author keywords analysis which is part of the scientometric analysis conducted in VOSviewer. Both table 2 and figure 5 serve as a visual aid for the qualitative analysis. As can be seen from table 2, in the group of Architectural Heritage (AH) the most occurring word is "HBIM", the remaining keywords such as "Automatic segmentation", "Grasshopper" , "Laser scanning and photogrammetry" are all related to HBIM. The strong links of HBIM to Architectural Heritage that are evident in this cluster are proof that HBIM is becoming an integral part of Architectural Heritage.

Whilst HBIM is still a valid field of research, many in the sector are seeing the Digital Twin as being a natural evolution of the implementation of more general 'BIM' and this is postulated by the research behind the Digital Twin group and the BIM group in the keywords analysis clusters. Moyano et al. (2022) indicated that the process of restoration of a historic building through HBIM should start with obtaining measured tangible data through remote sensing techniques, creating a point cloud to go through the scan-to-BIM process, processing the content of data applying ontologies to HBIM, classifying data and lastly evolving towards a Digital Twin. Massafra et al. (2022) discussed the steps towards developing a digital twin driven heritage assets management in heritage buildings.

Managing energy usage in heritage facilities is another aspect related to HBIM as evident from group 4 in the cluster analysis. Authors from this area namely Massafra et al. (2022) suggest using digital twins to achieve performance based heritage management. The digital twins can detect the conditions after a refurbishment in the building and will allow the sensor data collected around the conditions in the building to dictate the performance expectations and make recommendations for O&M through analytics (Massafra et al., 2022).

The importance of "heritage documentation" and "conservation and documentation" has been highlighted by several authors. Some authors pointed out that although each step of the conservation process requires participation from a diverse group of experts, there is no scientific record documenting a systematic approach for the complete process (Moyano et al., 2022). Moreover, pointing out that adopting a systematic approach to generate HBIM in restoration projects will support developing a DT of architectural elements for life-cycle management (Moyano et al., 2022). Similarly Guzzetti et al. (2022) called for a need to digitize the information asset of architectural heritage. The authors looked into associating the 3D model of a heritage building to different levels of data sets that include the history of the building, documentation, facility management, tourism fruition (Guzzetti et al., 2022).

4. Discussion

The above review and initial bibliometric analysis highlight significant correlation and focus of efforts in the field of BIM and a substantial body of work on HBIM. As would be anticipated, there is more limited research effort on the emerging application of digital twin to the field of architectural heritage and very limited focus of efforts in bringing together the knowledge of HBIM, Heritage and digital twins. This is an area that could yield significant benefits in the future as society looks to better reuse, adapt, and manage historic buildings for future and more sustainable use.

Specifically, there exists the potential to focus research in several areas:

- Retro installation of technologies to monitor performance
- Enhanced planned, preventative maintenance based on historic data
- Historic (retrospective) Twinning of heritage assets
- Improved generation of geometric twin data (or digital shadow) based on extensible intangible data sources

Retro installation of technologies to monitor performance

BIM has been integrated into the cultural heritage domain, the HBIM model has potential to evolve into a new method for managing heritage buildings and sharing data with building lifecycle operators (Massafra et al., 2022). The direction where the restoration of architectural heritage is heading, displays a need to develop a comprehensive digital environment for digital twining of the heritage-built assets that will help in overcoming any potential risks to the assets (Bruno et al., 2022). Future research should also look into constructing an efficient framework that shows the evolution of complex heritage structures in a virtual environment (Guzzetti et al., 2022).

Enhanced planned, preventative maintenance based on historic data

Managing heritage assets is a complex process as the projects often deal with scientific, structural and textual data (Moyano et al., 2022). Whilst HBIM is still a valid field of research, many in the sector are seeing the Digital Twin as being a natural evolution of the implementation of more general 'BIM'. HBIM process of restoration of a historic building should lastly evolve towards a Digital Twin (Moyano et al., 2022). Some researchers stress on the need to start a HBIM process with a more accurate architectural survey with a laser scanner and modelling each element of the building as it can be the basis of digital twin to support preventative maintenance in heritage buildings (Casillo et al., 2022).

Historic (retrospective) Twinning of heritage assets

Thus there is a need to digitize the information asset of architectural heritage (Guzzetti et al., 2022). Data collection phase aims to acquire preliminary information regarding the building typology, methods of construction, materials used, previous alterations as well as room layout and use. This data is obtained through archival and bibliographical data, existing drawings, historical memories and photographs (Bruno et al., 2022). Moyano et al2022) called for a systematic approach in every step when working with heritage buildings.

This indicates that the more accurate the data sets gathered at the initial stage through archival research, the more it can help identify properties and characteristics of the building that would otherwise be challenging to find. A survey identifies the current geometrical features of the heritage building (Massafra et al., 2022). Understanding the alterations of cultural heritage through time is a complex procedure, however it is essential in understanding and operating attentively on the heritage assets. (Guzzetti et al., 2022)

Improved generation of geometric twin data (or digital shadow) based on extensible intangible data sources

An operating model is needed to show the history of the architecture and manage its heritage data. The basic idea of a BIM model is to associate information to the model of the asset, similarly cultural heritage data must remain the pivot of a similar system (Guzzetti et al., 2022). Predominantly the creation of a HBIM is undertaken through the process of Scan-to-BIM with measured data obtained of tangible cultural heritage and then transposed through a manual process to a geometric model via the use of BIM authoring tools (Moyano et al., 2022) (Casillo et al., 2022). The conservation of both tangible and intangible data is essential for heritage buildings, as it helps to keep both the physical integrity of the heritage building and its value for the future generations (Casillo et al., 2022).

Where physical measured data is not available, for example where the building fabric is partially non-existent, other data sets (such as photographs or historic drawings) can be used to support the geometric modelling process (Bruno et al., 2022) (Casillo et al., 2022)(Guzzetti et al., 2022).

5. Conclusions

This research is the first to use bibliometric analysis to investigate the state of published articles linking DT to BIM and AH. The analysis revealed that there is not enough research conducted in this area to solve the issues surrounding architectural heritage restoration and conservation. The small amount of research indicates the need for further examinations and studies in the area. Based on the quantitative part of the analysis, it can be concluded that the number of scientific research papers grew since 2019 and reached 10 papers around the topic in 2023. The study contributes to the field and reveals a need to develop a comprehensive digital environment and an efficient framework that shows the process of evolution of complex heritage structures in a virtual environment. Based on the results of the co-authorship network analysis there are 7 countries currently involved in such research with Italy being the country with the most research in that field. The analysis also revealed that fragmentation and isolation between authors calling for more collaborative work and exchanging ideas. Keywords' analysis revealed that HBIM is becoming an integral part of the architectural heritage, however many in the sector identify digital twin as being a natural evolution of the implementation of BIM, discussing a need to develop a digital twin driven heritage assets management.

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The Use of Smart Contracts to Assist in Mitigating Payment Inefficiencies

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Abstract

Most projects are not being delivered on time because of disputes arising from payment inefficiencies. Unfair payment practices and inefficiencies exist within the construction industry, delays occur on projects, disputes arise between stakeholders; cost overruns occur, and overall project performance is poor. A construction contract provides a guideline for a project and forms the basis for control of procedures during construction. Smart contracts in turn, provide an opportunity to ensure that the guidelines set out in the construction contract are followed and adhered to. Using blockchain technology, smart contracts limit the amount of subjectivity relative to claims and disputes, payment, quality, risk, and time, ensuring that the parameters set and agreed upon in the formulation of the contract are maintained through the project life cycle.

Against this background, the study investigated the problem of poor payment practices and the use of an automated smart contract system to reduce payment inefficiencies and create optimisation within the construction industry. The study adopted a quantitative approach, the aim being to evolve a framework of interventions to address the challenges relative to payment inefficiencies, including the use of smart contracts.

Key findings include: the five key contributors to payment delays are extended waiting time for approval, deficiencies in coordination, delayed decision making, variation orders, and delayed information flow; there is a lack of knowledge relative to smart contracts and blockchain technology; a lack of adoption of Industry 4.0 technologies, and there is major interest regarding smart contracts.

Conclusions include: an up to date as-built model to track progress on projects speeds up payment approval, and minimises scope changes and rework; the greatest contributor to payment delays relates to stakeholders agreeing to progress; the implementation of smart contract systems to manage disputes, hinges on clients', contractors', and contractors' knowledge and understanding of construction contracts.

Recommendations include: a paradigm shift with respect to payment on projects; delayed payments on projects should be monitored; education of project stakeholders regarding smart contracts, and smart contracts should be implemented on projects to enable automated payment once certain conditions, variables, and principles have been met.

Keywords: Automation, Blockchain, Construction, Payment delays, Smart contracts.

1. Introduction

Compared to many other industries, the construction industry, plays a vital role in South Africa's economy and is a key contributor to economic growth (Windapo & Cattell, 2013). The industry is labour intensive providing employment opportunities for large sections of the nation's work force.

The South African construction industry is known for being unique with characteristics that contribute to payment problems. The industry is renowned for low capital backing; however, it relies heavily on cash flow to sustain operations, especially regarding small contracting firms and sub-contractors. Ramachandra and Rotimi (2015) contend that firms or individuals with little capital base and very limited experience can set up construction businesses. Omopariola and Windapo (2019) emphasise that developing and maintaining a healthy and competitive construction industry stems from smooth cash flow guarantees, which ensure the efficient delivery of construction projects.

The construction contract can assist in the management of a project and should provide security and peace of mind for all parties involved. However, many projects are not being delivered on time, disputes arise, and this negatively affects the construction industry. The reason is due to a lack of understanding and experience of construction contracts and their formulation and implementation during the project life cycle. According to Arditi and Chotibhongs (2005), the problems in the construction industry begin when payment of the exact amount due by the date shown on the statement is not received. Arditi and Chotibhongs (2005) further lament that disagreements then lead to arguments as relationships break down, attempts to shift the blame, and conflict ensue, and litigation follows. Ultimately, projects exceed initial time estimates, costs escalate, and delays are experienced.

The study aims to determine whether smart contracts using block chain technology can assist in mitigating payment inefficiencies and excludes studies that focus on specific smart contract systems, and which can be best implemented.

2. Review of the literature

2.1 Factors contributing to payment delays

Ramachandra & Rotimi (2015) reference Ye & Rahman (2010) who listed the top five causes of payment delays, namely poor financial management, ineffective utilisation of funds, lack of capital to finance projects, failure to source money from banks in times of reduced sales, delay in releasing retention monies to contractors, and delay in evaluation and certification of interim and final payments. Ramachandra & Rotimi, (2015) document that payment inefficiencies relate to inadequate processes and are largely attitudinal and could be refined to ensure smooth cash flow through the supply chain between contractors, principals, and subcontractors.

Further causes arise when contractors and the professional team fail to agree with onsite valuations of work, which disagreements result in conflict between clients and contractors, which in turn leads to conflicts dispute resolution, ultimately contributing to delayed payments (Ansah, 2011). These late payments have an immediate effect on cash flow which is key to contractors' and subcontractors' survival. A delay concerning payments often drive contractors to source additional funding through overdraft facilities, trade credit, and other means to meet cash flow demands. It should be noted that often these payment delays are often deliberate. Given that in recent years between 70 - 75% of the value of work is undertaken by subcontractors, such payment delays cripple subcontractors who rely on the cash flow to pay suppliers, staff, and operate (Ramachandra & Rotimi, 2015).

2.2 Poor performance on projects due to payment delays

Omopariola and Windapo (2018) and Omopariola and Windapo (2019), and prior thereto, Motawa & Kaka (2009), have investigated how payment systems and related impact projects and performance. They determined that current payment systems in use include interim payment, advance payment, stage payment, milestone payment, and payment on completion. Omopariola and Windapo (2019) point out that there is an underlying principle that governs these systems, and that is that clients make payments to contractors and stakeholders in different ways and at different times of the project. Ansah (2011) explains that when contractors fail to receive interim, and / or other payments on time or in accordance with the stipulated terms of the contract or the proper amount, these payment delays affect the performance of the contractor.

2.3 Disputes between stakeholders regarding payment inefficiencies.

Omopariola and Windapo (2019) state that "the delivery of successful quality projects and the ability to meet client requirements and resolve disputes between stakeholders is often affected by inappropriate payment systems in the construction industry." Other researchers such as Danuri, Munnaim, Rahman, & Hanid (2006) agree with Omopariola and Windapo (2019) and state that the main subject of disputes among construction stakeholders that lead to financial problems are payment related. Omopariola and Windapo (2019) contend that clients' choice of payment systems is not necessarily suitable to the project environment.

Ansah (2011) further contends that there are not many favourable outcomes or remedies for the affected party. The contractor can either initiate legal action for the recovery of money owed including the interest payable to them, or initiate arbitration proceedings to claim for damages incurred by their business. If the client continues to refuse to pay the contractor after numerous interim payments have been authorised by the contract administrator, the contractor may treat non-payment as a repudiation of the contract, and therefore the contractor can legally treat this repudiation as an offer to rescind the contract (Ansah, 2011).

Ansah (2011) concludes that clauses that address delayed payment must be included in contracts. These could be in the form of additional charges on overdue payments and the establishment of a payment department.

2.4 The concept of smart contracts

Smart contracts utilise protocols and user interfaces to facilitate all the steps in the contracting process. Lamb (2018) describes a smart contract as a contract using computer protocols to formalise elements of a relationship to automatically execute the terms encoded therein once the pre-defined conditions are met. The need for acceleration and automation of key processes is critical to the industry in terms of moving forward, and Altay & Motawa (2020) highlight how this can be achieved using smart contracts using blockchain technology.

A key feature of smart contracts is that transactions are performed without intermediaries. A blockchain consists of units of data pertaining to specific transactions arranged in an ordered list (Lamb, 2018), that allows the automation of transactions within a contract once certain predetermined project variables and principles are met (Altay & Motawa, 2020). Smart contracts enable greater traceability and provide an opportunity for an increase in processing efficiency.

2.4 How smart contracts have emerged as a potential solution to payment inefficiencies

Although there have been mechanisms put in to practice within standard forms of construction contracts, there is still an overwhelming issue of delayed payments within the construction industry (Omopariola and Windapo, 2019). Construction projects are a unique type of project in that multiple professional groups work alongside each other to achieve project success. This poses a problem regarding coordination. Automation through digitalisation in construction can assist in addressing coordination deficiencies to reduce disputes between stakeholders on projects (Altay & Motawa, 2020). According to Altay and Motawa (2020), digital construction aims to increase collaboration among project stakeholders. Furthermore, Altay and Motawa, (2020) describe how the simulation feature in smart contracts reduces coordination deficiencies.

The industry has attempted to resolve the problem of payment delays and progress has been made. Adapting to advancements in technology is a limiting factor when trying to mitigate payment inefficiencies, there is technology available to assist. Smart contracts, if implemented correctly should have the potentially to solve or reduce important issues regarding payment delays and make a meaningful contribution to overall project performance (Altay & Motawa, 2020).

3. Research

3.1 Research Method and Sample Stratum

The quantitative method was adopted for the study, which entailed an online questionnaire survey. The sample included 65 potential respondents who were registered with statutory councils and members of employer associations in the Nelson Mandela Bay Metropole, and in the case of individuals, from 18 to over 65 years of age, and having worked in the construction industry for more than one calendar year. The respondents included architects, engineers, construction project managers, engineers, general contractors, project control consultants, quantity surveyors, and subcontractors. 33 Responses were included in the data analysis, which entailed the computation of frequencies, and a measure of central tendency in the form of a mean score (MS), which equates to a 50.8% response rate. The questionnaire consisted of forty-four questions – forty-three closed-ended, and one open-ended. Thirty-five of the close-ended were Likert scale type questions and eight were demographic related questions.

3.2 Results

Table 1 indicates the extent to which nine factors contribute towards payment delays during construction projects in terms of percentage responses to a scale of 1 (minor) to 5 (major) and mean scores (MSs) ranging between 1.00 and 5.00. It should be noted that all the MS's are above the midpoint score of 3.00, which indicates that in general these factors contribute to payment delays during construction projects to more of a major, as opposed to a minor extent.

It is notable that 6 / 9 (66.7%) factors have MSs $> 3.40 \leq 4.20$, which indicates they contribute between some extent to a near minor / near minor extent. Extended waiting time for approval is ranked first followed by deficiencies in coordination, delayed decision making, variation orders, delayed information flow, and lack of communication. 3 / 9 (33.3%) of factors have MSs > 2.60 ≤ 3.40, which indicates the contribution is between a near minor extent to some extent / some extent - non-utilisation of professional construction / contractual management is followed by inaccurate estimates, and poor site management. These findings indicate that the causes are multi-stakeholder in terms of origin, and several can be mitigated by smart contracts.

Table 1. Extent to which nine factors contribute to payment delays during construction projects.

Factor	Response (%)						MS	Rank
		Minor……………………..Major						
	Un-sure	1	2	3	4	5		
Extended waiting time for approval	0.0	0.0	9.1	15.2	39.4	36.4	4.03	1
Deficiencies in coordination	3.0	3.1	3.1	15.6	46.9	31.3	4.00	2
Delayed decision making	0.0	3.0	9.1	15.2	36.4	36.4	3.94	3
Variation orders	0.0	3.0	15.2	18.2	30.3	33.3	3.76	4
Delayed information flow	0.0	3.0	9.1	18.2	48.5	21.2	3.76	5
Lack of communication	0.0	12.1	18.2	15.2	24.2	30.3	3.42	6
Non-utilisation of professional construction / contractual management	6.1	6.5	19.4	25.8	25.8	22.6	3.39	7
Inaccurate estimates	0.0	9.1	18.2	18.2	39.4	15.2	3.33	8
Poor site management	3.0	9.4	18.8	37.5	28.1	6.3	3.03	9

Table 2 indicates the frequency at which phenomena occur on projects in terms of percentage responses to a scale of never to always, and MSs ranging between 1.00 and 5.00. It is notable that 6 / 10 (60.0%) of MSs are above the midpoint score of 3.00, which indicates that in general the phenomena occur frequently, as opposed to infrequently. The mean score is 3.26, the regularity that payment delays and/ or disputes on projects occur can be deemed to be from sometimes too often.

It is notable that 5 / 10 (50.0) % of MSs are > 3.40 ≤ 4.20, which indicates that the frequency is between sometimes to often / often. A further 3 / 9 (33.3%) phenomena have MSs > 2.60 ≤ 3.40, which indicates the frequency is between rarely to sometimes / sometimes. The remaining phenomenon's MS is > 2.60 ≤ 3.40, which indicates the frequency is between never to rarely / rarely. To summarise, payment delays and / or disputes are occurring on projects and the frequency is related to time overruns, scope changes, mismanagement of funds, withholding of funds and disputes between stakeholders which is resulting in non-conforming work and rework, vandalism of projects, and cost overruns.

Table 2. Frequency phenomena occur.

Phenomenon	Response (%)						MS	Rank
	Unsure	Never	Rarely	Sometimes	Often	Always		
Payment related disputes arise between stakeholders	9.1	0.0	13.3	16.7	46.7	23.3	3.80	1
Withholding of payments result in disputes on projects	3.0	6.3	6.3	25.0	43.8	18.8	3.62	2
Payments delays and / or disputes result in time overruns	6.1	0.0	16.1	25.8	38.7	19.4	3.61	3
Payment delays occur on projects that our firm is involved in	0.0	3.0	21.2	24.2	27.3	24.2	3.48	4
Mismanagement of finances result in payment delays	3.0	6.3	12.5	21.9	46.9	12.5	3.47	5
Late payments cause project cost overruns	3.0	6.3	18.8	28.1	37.5	9.4	3.25	6
Rework	6.1	6.5	22.6	38.7	29.0	3.2	3.00	7
Quality of work is sacrificed because of late payment and / or non-payment	6.1	12.9	19.4	32.3	29.0	6.5	2.97	8
Payment delays result in scope changes	0.0	6.1	24.2	45.5	18.2	6.1	2.94	9

Construction projects are vandalised and / or damaged because of payment delays and / or disputes	9.1	20.0	36.7	33.3	0.0	10.0	2.43	10

Table 3 presents the impact of late payments on project performance in terms of percentage responses to a scale of 1 (minor) to 5 (major), and a MS ranging between 1.00 and 5.00. It is notable that 6 / 7 (85.7%) MSs are above the midpoint of 3.00, which indicates that in general the impact is more major as opposed to minor. 4 / 7 (57.1%) MSs are > 3.40 ≤ 4.20, which indicates that the impact is between an impact to a near major / near major impact. A further 2 / 7 (28.6%) MSs are > 2.60 ≤ 3.40, which indicates the impact is between near minor to an impact / impact. The remaining MS is > 1.80 ≤ 2.60, which indicates the frequency is between minor to near minor / near minor. These findings indicate that there is a link between late payments and poor project performance. Poor productivity and time overruns predominate, which presents several problems for the stakeholders in terms of escalation, compensation for increased preliminaries costs, as many other costs, which are time related and calculated accordingly. These, cost overruns and quality-related issues impact negatively on profit margins, and many affect the reputation of the parties involved.

Table 3. Impact of late payments on performance.

Aspect / Impact	Response (%)						MS	Rank
	Un-sure	Minor……………………..				..Major		
		1	2	3	4	5		
Productivity	6.1	0.0	3.2	22.6	71.0	3.2	3.74	1
Time overruns	0.0	3.0	12.1	12.1	57.6	15.2	3.70	2
Cost overruns	6.1	6.5	3.2	32.3	45.2	12.9	3.55	3
Reduced profit margin	3.0	12.5	9.4	15.6	50.0	12.5	3.41	4
Quality	3.0	6.3	15.6	28.1	40.6	9.4	3.31	5
Tarnishing of reputation of parties involved in the project	3.0	6.3	25.0	28.1	31.3	9.4	3.12	6
Health and safety	3.0	18.8	43.8	25.0	12.5	0.0	2.31	7

Table 4 indicates whether respondents understand what a smart contract is or not. Almost half (48.5%) responded 'No' and notably, 21.2% were 'Unsure'. Only 30.3% responded 'Yes', and of those who responded yes only 60% answered correctly when asked to provide a definition for a smart contract.

Table 4. Respondents understand smart contracts.

Response	Frequency	%
Yes	10	30.3
No	16	48.5
Unsure	7	21.2
Total	33	100.0

Table 5 indicates the extent to which smart contracts could assist in reducing payment delays by means of seven paths during construction projects in terms of percentage responses to a scale of 1 (minor) to 5 (major), and MSs ranging between 1.00 and 5.00. It is notable that all the MSs are > 3.00, which indicates smart contracts could assist to a major, as opposed to a minor extent. Only 1 / 7 (14.3%) MSs is > 4.20 ≤ 5.00, which indicates that the extent is between near major to major / major – eradicating corruption. The remaining 6 / 7 (85.7%) MSs are > 3.40 ≤ 4.20, which indicates smart contracts could between some extent to a near major / near major extent assist in reducing payment delays. Clearly smart contracts are perceived to have the potential assist in reducing payment delays.

Table 5. Extent to which smart contracts could assist in reducing payment delays by means of seven paths.

Path	Response (%)						MS	Rank
	Un-sure	Minor……………………..				..Major		
		1	2	3	4	5		
Eradicating corruption	12.1	0.0	0.0	10.3	48.3	41.4	4.31	1

Minimising malicious or accidental errors in payments	12.1	0.0	6.9	6.9	55.2	31.0	4.10	2
Using blockchain technology to assist in payment automation	18.2	0.0	3.7	11.1	63.0	22.2	4.04	3
Providing greater efficiency within the construction industry	15.2	0.0	3.6	17.9	57.1	21.4	3.96	4
Increasing project performance and productivity	12.1	0.0	6.9	24.1	51.7	17.2	3.79	5
Decreasing stakeholder disputes	12.1	0.0	3.5	31.0	55.2	10.3	3.72	6
Decreasing cost overruns	12.1	3.5	13.8	20.7	51.7	10.3	3.52	7

Table 6 indicates that only 27.3% of the respondents opined that smart contracts could be implemented in the South African construction industry. However, it is notable that 45.45% felt that smart contracts could not be implemented. 27.27% of the respondents were unsure which indicates that either there are barriers to entry of the smart contract system or more information is required to answer this question effectively.

Table 6. Possibility of implementation of smart contracts in the South African construction industry.

Response	Frequency	%
Yes	9	27.3
No	15	45.5
Unsure	9	27.3
Total	33	100.0

4. Discussion

The findings revealed that there are five key areas contributing to payment delays. These factors are extended waiting time for approval, deficiencies in coordination, delayed decision making, variation orders, and delayed information flow. Given these findings, payment inefficiencies and delays can be deemed to relate to inadequate processes and are largely attitudinal.

In terms of payment inefficiencies contributing to disputes between stakeholders, the top three factors include: the frequency payment-related disputes arise between stakeholders; withholding of payments result in disputes on projects, and the frequency that payments delays and / or disputes resulted in time overruns. Omopariola and Windapo (2019) state that the delivery of successful quality projects and the ability to meet client requirements and resolve disputes between stakeholders is often affected by inappropriate payment systems in the construction industry. It is also notable from the literature that the main subject of disputes among construction stakeholders are payment-related. Furthermore, the project environment needs to align with the client's choice of payment systems (Omopariola and Windapo, 2019).

The findings reveal that the majority of respondents are either unsure or do not know what a smart contract is. The majority of respondents indicated that smart contracts could assist in payment automation and provide greater efficiency in the construction industry. They also perceive that smart contracts have a role to play in terms of eradicating corruption. Another key consideration is that the respondents perceive that smart contracts can improve project performance and productivity, while decreasing cost and time overruns as well as minimising malicious or accidental errors in payments.

It is evident from the study that the use of smart contracts has the potential to eradicate corruption, minimise malicious or accidental errors in payments, and to assist in payment automation. It is evident from the literature that there is a great need for transparency and optimisation of payments in the construction industry. Adapting to advancements in technology is a limiting factor when trying to mitigate payment inefficiencies. Possible disputes that may occur among the stakeholders in the project can be reduced as transaction approvals in the blockchain system require joint action, which automatically promotes collaboration among parties.

5. Conclusions

This study aimed to investigate the problem of poor payment practices and the use of an automated smart contract system to reduce inefficiency and create optimisation within the South African construction industry. This was done through identifying the factors that contribute to payment delays during construction projects while examining why payment disputes arise between stakeholders on projects. In conjunction with this literature examining the extent to which non-payment and / or late payments can influence project performance and cost overruns was reviewed. The extent to which smart contracts can be utilised to assist in reducing payment delays was reviewed and evaluated.

Conclusions include: having an up to date 'as-built' model to track progress on projects speeds up payment approval and minimises scope changes and rework. The greatest delays towards payment relate to stakeholders agreeing with respect to progress, which is a result of contractors not submitting the correct information to substantiate progress. In terms of payment disputes between stakeholders and the implementation of smart contract systems to manage these disputes, contractors', clients', and consultants' knowledge and understanding of construction contracts is important. Educating stakeholders with respect to any contracting system is key. However, incorporating a smart contract system where automation can occur after certain predetermined parameters are met will create greater efficiency and decrease cost and time overruns. The successful implementation of smart contracts in the South African construction industry has the potential to solve or reduce payment issues and delays and result in greater overall project performance. The literature also reveals that for this to be implemented there needs to be incentives for stakeholders to implement the blockchain enabled payment and project management systems. Furthermore, the question arises as to whether the public sector in the form of government and state-owned enterprises will embrace this approach, or not. The mitigation of corruption due to the nature of smart contracts and blockchain technology constitutes the incentive, if the public sector is committed to combatting corruption.

6. Recommendations

There should be no doubt that any construction project will experience delays in coordination and information flow, which in turn result in scope changes and ultimately, stakeholder frustrations. There should be more awareness and attention given to stakeholders withholding payments. There should be more attention given to the stakeholders who experience the effects of late payments, which effects have a detrimental effect on project performance, and result in non-conforming work. Although there have been mechanisms included in standard forms of construction contracts, there is still the overwhelming issue of delayed payments within the construction industry. Automation through digital construction can assist in coordinating deficiencies to reduce disputes between stakeholders on projects.

There is a lack of knowledge relative to smart contracts and blockchain technology, followed by non-implementation, and a lack of adoption towards new technology and willingness to change towards industry 4.0 technology. What is crucial is that an acceptable smart contract model for payment automation and progress confirmation is selected. All parties need to agree with respect to the system to be implemented, and that these models are applicable for the type and nature of a particular project.

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Exploring Digital Risk Management for Building Life Cycle Phases

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Abstract

Technology adoption in the building industry is predominantly implemented to improve risk management procedures. The impact of digitalisation on risk management is a key aspect to address as it has a major influence on all stages of construction. Many studies have examined the risks associated with the building and construction industry. However, only a few have explored the risks associated with classified building life cycle phases. This study explores the opportunities for digital technologies to manage risk across the five phases of the building life cycle: pre-design, design and engineering, construction, operation and maintenance, and deconstruction. The data collected and analysed in this study shows that digital technologies significantly influence risk management during the design and engineering phase of the building life cycle. This is followed by the pre-design, operation and maintenance, and construction phases, with the deconstruction phase having the lowest influence. The use of digital technologies can help reduce risks associated with site conditions, design errors, construction accidents and delays, energy waste, equipment failures, and environmental pollution and health hazards. Digital technologies can be leveraged to ensure that buildings are designed, constructed, and maintained to the highest safety, sustainability, and efficiency standards. By embracing these technologies, architects, engineers, and construction professionals can revolutionise the construction industry, ensuring that buildings are constructed safely, sustainably, and efficiently. The findings of this study demonstrate the potential of digital technologies to mitigate risks across the building life cycle phases and highlight the need for continued research and development in this area.

Keywords

Digitalisation, Risk management, Digital Risk Management, Construction industry, Building Life Cycle.

1. Introduction

Over the last few years, the construction industry has undergone a radical transformation with the integration of digital technologies (Akinshipe, et al., 2022). Traditional risk management is still a manual process, with evaluation largely dependent on experience and numerical analysis, and decision-making often focused on expertise and experience-based judgements, both of which result in lower effectiveness in the modern world (Shim et al., 2012). Traditional approaches for analysing project risk have been chastised for its shortcoming in considering the structural nature of the construction management process (Akintoye & MacLeod, 1997). The incline in the number of accidents, injuries, deaths, theft, shortage of resources and loss of time and money, all of which leads to risk, shows that although there is risk management in the construction industry, it has not been managed with full efficiency (Meno, 2020). Technology adoption is mainly implemented to enhance risk management (Ernst & Young, 2016). The impact of digitalisation on risk management is a key aspect to address as it has a major influence on all stages of construction. Using digital tools can impact a project's success factors like time, budget, and safety. By understanding how digitalisation affects risk management, digital platforms can be used more effectively to manage project risks (Meno, 2020). This can lead to growth in the construction industry due to reducing risk factors such as health and safety hazards, theft, change orders, etc., leading to successful project delivery throughout the project life cycle (Aghimien et al., 2021). While numerous studies have been conducted on risks associated with the building and construction industry, only a few have specifically examined risks related to the different phases of the building life cycle. This study explores how digital technologies influence risk management in various building life cycle phases.

2. Digital Technologies for Risk Management in Building Life Cycle Phases

Over the last few years, the construction industry has radically transformed by integrating digital technologies. This has revolutionised the way buildings are designed, constructed, and maintained. With the introduction of innovative technologies such as Building Information Modeling (BIM), drones, and sensors, the different phases of the building life cycle (Akinradewo et al., 2018). These phases include pre-design, design and engineering, construction, operation and maintenance, and deconstruction. These digital technologies have immense potential to reduce risks associated with construction projects, especially in ensuring the safe, sustainable, and efficient construction of buildings.

2.1 Pre-Design Phase

The inception or pre-design phase is critical to building project management, encompassing all necessary work before project approval and planning. During this phase, the client typically proposes the project idea, creating a client brief to direct and animate the project (Akinshipe et al., 2019a). The client brief is a written document that provides the organisation in charge of the project with specific information about the project. It serves as a template to synchronise project stakeholders and improve team cohesion (Akinshipe et al., 2019b). Another crucial task in this phase is conducting a feasibility study, which examines pertinent aspects of the project, including economic, technical, legal, and scheduling factors, to determine its chances of success (Aigbavboa et al., 2020). Historically, digital technologies have not played a large role in executing these activities successfully. However, Aghimien et al. (2018) identified three key phases for deploying digital technology in the life cycle of construction projects: design/engineering, construction, and operation/maintenance.

Although the pre-design phase is not typically considered a primary phase for technology deployment in construction projects, technologies can still be utilised to some extent. This phase requires extensive communication and collaboration between stakeholders, their representatives, and the agency working on the project. Technologies such as ICT can facilitate communication, hold meetings, and transfer documents, thereby reducing administrative costs and saving time. Additionally, drones can provide an overview of the site and its surroundings, aiding in collecting data for the client brief and feasibility studies. Effective data gathering can help mitigate and manage some risks at this project stage. Smith, Love & Heywood (2005) conducted a study on creating a performance brief during the inception stage of a project and identified computer software packages that could be used for this purpose. In the pre-design stage, digital tools like BIM can assist architects and engineers in site analysis and selecting the best building materials and construction techniques.

2.2 Design and Engineering Phase

A building project involves several stages and can take years to complete, and the quality of the final product is influenced by how effectively each stage is executed. However, the engineering planning and design phases, which is critical to the project's success, are often overlooked (Tan & Lu 1995; Aghimien, et al., 2021). Design involves transforming an idea, theory, or notion into a drawing, plan, specification, model, or other media that enables a set of goals to be met or constructed. Over the past few decades, project managers, engineers, architects, and researchers have developed digital technologies and processes to address coordination and collaboration issues in the design and delivery of major building and infrastructure projects (Ibrahim, 2011). BIM and Computer Aided Design software are highly recommended during the design and engineering phase, as they facilitate a cohesive working unit among the specialists who comprise the design team (Ikuabe et al., 2020).

Building design and engineering for large construction projects have become increasingly complex in recent years, but digital design tools can assist. Three-dimensional modelling can be used to design entire projects, which can help identify potential design clashes and constructability issues. Architects frequently use Building Information Modeling (BIM), with 43% of them using it on more than 60% of their projects, reducing the use of previous designing methods (Ibrahim, 2011). Furthermore, digital design and engineering tools have opened up new possibilities, allowing for the fabrication and construction of highly complex forms that were previously impossible using traditional building methods (Kolarevic, 2001). In the design stage, digital technologies can aid in the design and engineering stage by spotting any defects in the proposed designs and allowing engineers and architects to make the necessary corrections before construction starts.

2.3 Construction Phase

The construction phase of a project is responsible for implementing the planning and scheduling previously done in the design phase (Mueller, 1996). According to Aghimien et al. (2018), this phase is crucial for deploying digital technologies, as has been done in the past. Recently, the first 3D-printed house in Germany was completed and has garnered attention for its impressive design and has even won the “German Innovation Award” for 2021 (Madelein, 2021). Additionally, Castagnino et al. (2016) demonstrated how digital technologies were utilised during the construction phase of the Crossrail project, one of the most complex infrastructure projects globally.

Castagnino et al. (2016) reported that the Crossrail project utilised various advanced technologies like drones for inspections, 3D printing for materials, RFID trackers for monitoring materials and labour, and robots, among others. In addition, Tomek (2014) explained that BIM could be utilised for various tasks during the building phase, such as present condition modelling, budgeting, task review, certification, and site analysis. The Internet of Things (IoT) also has numerous applications in the construction phase, with sensors-equipped equipment for tracking tools, transportation, health and safety, security, and detecting faults in building components (Oke, et al., 2020). In addition to that, ICT could also be utilised during construction through mobile applications, which are used to generate, save, access, and organise project management activities and plans on building sites. During the construction phase, digital tools can be used to track construction development and spot potential problems like accidents and delays during the construction period.

2.4 Operation and Maintenance Phase

Various institutions, including corporations, school districts, hospitals, and governmental bodies, invest billions of dollars in constructing facilities and infrastructure systems. However, spending money on facilities doesn’t end after the completion of construction. Facilities must be maintained to ensure they meet their intended purpose. According to Pati, Park, & Augenbroe (2010), facility design is increasingly important in achieving strategic organisational goals. However, facility maintenance challenges are frequently overlooked in decision-making. The traditional gap between facility design and maintenance stems from a lack of a meaningful way to express, analyse and interpret facility maintenance data during design decision-making. Fortunately, with digital technology available today, facility management and maintenance are becoming one of the fastest-growing real estate and construction services, and it has become a hot issue for research (Lin, Su, & Chen 2012).

According to Chen et al. (2018), Building Information Modelling (BIM) is a new construction and facility management approach that creates a digital database of a building’s assets and enables virtual 3D coordination of construction and operational activities, including facility management. BIM has been identified as a contributor to facility management by providing information and acting as a repository to aid in planning and administering building maintenance activities for new and existing structures. The construction industry has recognised the potential benefits of BIM for facility management (Liu & Issa 2016). Araszkiewicz (2017) identified several facility management tasks that IT solutions could support. These include creating safety assessment documents, estimating reliability, managing assets, planning and overseeing renovations, tracking and managing maintenance issues through helpdesk systems, and managing space. Digital technology can track the building’s energy use during operation and maintenance and spot problems such as equipment breakdowns and system faults.

2.5 Deconstruction Phase

In recent decades, there has been a significant increase in knowledge among owners, engineers, and contractors about the importance of sustainability in the building sector and the economic benefits of deconstruction (Akbarnezhad, Ong & Chandra 2014). The US EPA reports that building repair and demolition materials debris accounts for 25 to 30 % of all garbage produced in the United States each year (Guy, Shell, & Esherick 2006). Similarly, buildings in Sweden account for 40% of their energy consumption and 30% of the waste stream (Kanters 2018). The waste produced by building demolitions is a global issue. As a result, Akbarieh et al. (2020) explored using BIM for End of Lifecycle scenario selection to minimise construction and demolition waste. They found seven mainstream uses of BIM-based End of Lifecycle, such as Social and cultural factors, BIM-based Design for Deconstruction BIM-based deconstruction, BIM-based End of Lifecycle within Life Cycle Assessment, BIM-aided waste management, Material and Component Banks, off-site construction, interoperability, and Industry Foundation Classes. Akbarieh et al. (2020) concluded their study by stating that “BIM facilitates deconstruction planning and execution and enables a culture for digital deconstruction as a part of a sustainable and circular Building Stock". Digital technologies can be utilised to identify hazardous materials and choose the best techniques for disposal or recycling during the deconstruction phase.

Table 1. Digital technologies for risk management in building life cycle phases.

S/N	Digitalisation Risks	Useful Digital Technologies	Reference
1	Pre-Design phase	BIM, 3D scanning and mapping tools, GIS Software, Environmental simulation and analysis software, Extended reality technology, IoT technology, Risk management software, Data analytics software, Project management software	Aghimien et al. (2018); Smith, Love and Heywood (2005)
2	Design and Engineering phase	BIM, Energy modelling software, Extended reality technology, GIS Software, Risk management software, Project management software	Tan & Lu (1995); Ibrahim (2011); Ikuabe et al. (2020); Kolarevic (2001)
3	Construction phase	BIM, Drones, Wearable Technology, Extended reality technology, IoT technology, Safety Management Systems, Digital Cameras, Mobile applications, Project management software	Aghimien et al. (2018); Madelein (2021); Castagnino et al. (2016); Tomek (2014); Oke, Arowoiya, and Akomolafe (2020);
4	Operation and Maintenance phase	Building Automation Systems, IoT technology, building management Software, Predictive Maintenance Tools, Extended reality technology, Remote Monitoring and Control Systems, BIM	Pati, Park, and Augenbroe (2010); Lin, Su, & Chen (2012); Chen et al. (2018); Liu & Issa (2016); Araszkiewicz (2017),
5	Deconstruction phase	BIM, Construction planning software, Digital documentation systems, Mobile applications, Extended reality technology, Drones, Robotics and Automation, Environmental monitoring systems	Akbarnezhad, Ong and Chandra (2014); Guy, Shell, & Esherick (2006); Kanters (2018); Akbarieh et al. (2020); Akbarieh et al. (2020)

3. Research Methods

This research is descriptive by design as it explores the opportunities for digital technologies to manage risk in various phases of the building life cycle. The survey respondents were all working professionals in the construction industry in South Africa. The study relied on eighty-two usable survey responses from industry experts retrieved for analysis. In order to quantify the significance of each rating, the five-point scale questionnaire was analysed and transformed into Mean Scores. The validity of the collected data was examined with the help of Cronbach's alpha. A result of 0.842 was returned, indicating that the internal consistency of the direct constructs was within the acceptable values. All respondents are working professionals from the building sector, with the majority being Quantity Surveyors. Participants in the study also included other built environment professionals with experience in the execution of construction projects. The majority of the participants of the study possess at least a Bachelor's Degree, with some possessing advanced degrees. The study participants are evenly distributed in the amount of experience the possess in the field, cutting across one and fifteen years. Only a small fraction of the group possesses more than fifteen years of experience. Furthermore, it is essential to note that the engagement sector is fairly evenly split between the public and private sectors and that many participants work as contractors, consultants and client's representatives. The relatively even distribution of respondents enhances the reliability of this study.

4. Results and Discussions

The study identified five phases of the building life cycle: the pre-design phase, the design and engineering phase, the construction phase, the operation and maintenance phase, and the deconstruction phase. For each phase, the study assessed digital technologies' influence on risk management, calculated the Mean and standard deviation, and ranked them. The data shows that the design and engineering phase had the highest mean score of 3.99, indicating that digital technologies significantly influence risk management during this phase. The standard deviation for this phase was 0.962, which suggests that the responses were tightly clustered around the Mean. The pre-design phase had a mean score of 3.84, with a slightly higher standard deviation of 0.949. The operation and maintenance phase had a mean score of 3.56, with a slightly lower standard deviation of 0.918. The construction phase had a mean score of 3.51, with a higher standard deviation of 1.033. Finally, the deconstruction phase had the lowest mean score of 2.95, with the highest standard deviation of 1.246.

Table 2. Exploring the use of digital technologies for risk management in building life cycle phases.

Digitalisation Risks	Mean Score	Std Deviation	Rank
Design and Engineering phase	3.99	0.962	1
Pre-Design phase	3.84	0.949	2
Operation and Maintenance phase	3.56	0.918	3
Construction phase	3.51	1.033	4
Deconstruction phase	2.95	1.246	5

The rank column shows the ranking of the building life cycle phases based on the mean score, with the design and engineering phase ranked first, followed by the pre-design phase, operation and maintenance phase, construction phase, and deconstruction phase, ranked fifth. Overall, the data suggests that digital technologies significantly influence risk management during the design and engineering phase of the building life cycle, followed by the pre-design, operation and maintenance, and construction phases. The deconstruction phase has the lowest influence, as indicated by the lowest mean score and the highest standard deviation.

The findings align with the findings of Aghimien et al. (2018), which noted that there are three major phases in the deployment of digital technology in the life cycle of construction projects: the design/engineering phase, the construction phase, and the operation and maintenance phase. However, this study reveals a new addition to the major phases in which digital technologies are deployed. The study shows that the pre-design phase is ranked second among the five listed phases. The theoretical study mostly shows the limited use of digital technology in the pre-design phase. However, the second positioning of the pre-design phase is very true. This phase involves many tasks and important pre-design activities currently being undertaken with the help of technology. This technology may not be a sophisticated hardware technology but rather a more basic technology such as ICT.

It is no secret that the adoption of digital technologies has increased by margins. However, the studies' findings reveal that digitalisation in the construction industry is more visible in the planning phases than during the execution phases. This implies that companies are more worried about the scheduling, planning, costing, and business aspect of the project than the physical executions of the project. Technologies are generally used for management, information communication, storage, and retrieval. This capability allows you to track projects and share reports more quickly while automatically documenting verification of what was conveyed. More essential digital technologies such as IoT to remotely control machinery and robots are uncommon to the industry which can be utilised in construction phases to reduce risk. This reduces the effort required for labourers, improving workers' health and safety and extending their working life in the construction industry. The construction industry has not fully reaped the benefits of the digital world.

In recent years, digital technologies have revolutionised the construction industry, transforming how buildings are designed, constructed, and maintained. Digital technologies such as Building Information Modelling (BIM), drones, and sensors have greatly impacted various phases of the building life cycle, including the pre-design phase, design and engineering phase, construction phase, operation and maintenance phase, and deconstruction phase. These technologies can potentially mitigate risks in the construction industry, ensuring that buildings are constructed safely, sustainably, and efficiently.

In the pre-design phase, digital technologies such as BIM can help architects and engineers analyse the site and determine the most suitable building materials and construction methods. This can help reduce risks associated with site conditions, ensuring that the building is constructed on a suitable site and with suitable materials. The digital tools useful for the pre-design phase include BIM, 3D scanning and mapping tools, GIS Software, Environmental simulation and analysis software, Extended reality technology, IoT technology, Risk management software, Data analytics software, and Project management software. These tools can help identify and manage risks related to site selection, environmental impacts, safety hazards, and other factors that may affect the building design and construction process.

In the design and engineering phase, digital technologies can help identify potential design flaws, allowing architects and engineers to make necessary adjustments before construction begins. This can help reduce risks associated with design errors, ensuring that the building is constructed to meet the desired standards. The digital tools useful for the design and engineering phase include BIM, Energy modelling software, Extended reality technology, GIS Software, Risk management software, and Project management software. These tools can help identify and manage risks related to site design, planning and orientation, IEQ impacts, Energy consumption, time-budget-resource usage, safety hazards, and other factors that may affect the building design and construction process.

During the construction phase, digital technologies can be used to monitor the progress of the construction and identify potential hazards such as accidents and delays. This can help reduce risks associated with construction accidents and delays, ensuring the building is constructed safely and efficiently. The digital tools useful for the construction phase include BIM, Drones, Wearable Technology, Extended reality technology, IoT technology, Safety Management Systems, Digital Cameras, Mobile applications, and Project management software. These tools can help identify and manage risks related to construction activities, Environmental impacts, Energy consumption, time-budget-resource usage, safety hazards, and other factors that may affect the construction process.

In the operation and maintenance phase, digital technologies can monitor the building's energy usage and identify potential issues such as equipment failures and system malfunctions. This can help reduce risks associated with energy waste and equipment failures, ensuring that the building operates efficiently and sustainably. The digital tools useful for the operation and maintenance phase include Building Automation Systems, IoT technology, Building management Software, Predictive Maintenance Tools, Extended reality technology, Remote Monitoring and Control Systems, and BIM. These tools can help identify and manage risks related to operational and maintenance activities, Energy consumption, budget-resource usage, safety hazards, and other factors that may affect the maintenance process.

Finally, in the deconstruction phase, digital technologies can be used to identify hazardous materials and determine the most appropriate methods for disposal or recycling. This can help reduce environmental pollution and health hazard risks, ensuring the building is deconstructed safely and sustainably. The digital tools useful for the deconstruction phase include BIM, Construction planning software, Digital documentation systems, Mobile applications, Extended reality technology, Drones, Robotics and automation, and environmental monitoring systems. These tools can help identify and manage risks related to deconstruction design and planning, as well as Environmental impacts, Energy consumption, time-budget-resource usage, safety hazards, and other factors that may affect the success of building deconstruction.

Using these technologies, stakeholders can make informed decisions, reduce project costs and timelines during the entire building life cycle process, and ensure the built environment's safety and sustainability. In conclusion, digital technologies can potentially revolutionise the building and construction industry by mitigating risks in various building life cycle phases. Construction professionals should embrace these technologies to ensure buildings are constructed safely, sustainably, and efficiently. By leveraging digital technologies such as BIM, drones, and sensors, the construction industry can ensure that buildings are designed, constructed, and maintained to the highest safety, sustainability, and efficiency standards.

5. Conclusion

This study aims to explore the opportunities for digital technologies to manage risk in various phases of the building life cycle. As we know, construction takes place in various phases, undertaken by various professionals. The literature discusses the pre-design phase, design and engineering phase, construction phase, operation and maintenance phase, and the deconstruction phase in relation to managing risk with digital technology. The phases mentioned consists of diverse task that contains risks. The literature discusses those tasks and the involvement of digital technologies to manage or mitigate the risk involved in the tasks.

The findings reveal that the design and engineering phase use available technologies most, followed by the pre-design, operation, maintenance, construction, and deconstruction phases. According to the literature, planning and engineering, construction, and operation and maintenance phases are the major phases in which technologies are adopted. However, digital technologies can potentially revolutionise the construction industry by mitigating risks in various building life cycle phases. Building professionals should embrace these technologies to ensure that buildings are constructed safely, sustainably, and efficiently. By leveraging digital technologies, the construction industry can ensure that buildings are designed, built, and maintained to the highest safety, sustainability, and efficiency standards.

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Synthesizing Construction Professionals' Perception of Construction 4.0 in South Africa

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Abstract

The construction industry is attributed to its slow compliance with the uptake of technological innovations. This has inhibited the industry from attaining projected heights characterised by these technologies' espousal. Construction 4.0 serves as a vehicle for the digital transformation of the methods and processes involved in construction project delivery. Therefore, this study seeks to present the viewpoints of construction professionals on the impacts of construction 4.0 in South Africa. Using a quantitative approach, a questionnaire survey was employed to elicit responses from target respondents. The retrieved data were subjected to statistical analysis using methods which included mean item score, standard deviation, and one-sample *t*-test. Findings from the study showed that the professionals' views indicate that the most significant impacts of the implementation of construction 4.0 are improved delivery time of projects, more accurate construction methods and increased customer satisfaction. It was also shown that all the identified impacts were proven to be significant. Conclusively, the study made recommendations that would aid in propagating the concept of digital transformation in project delivery using construction 4.0 as a viable vehicle. The study's outcome makes insightful contributions to the body of knowledge on the digitalisation of construction processes for effective project delivery.

Keywords

Construction 4.0, Construction Professionals, Digitalisation, Project Delivery, South Africa.

1. Introduction

Activities such as the erection of buildings and civil engineering projects and the maintenance and repair of existing structures characterise the mandates of the construction industry. According to the CIDB (2017), the construction industry plays a crucial role in job creation in South Africa, not only in the construction sector but also in other industries (e.g. material manufacturing, mining quarrying, and transport sector) that contribute to the South African economy. The importance of this sector cannot be over-emphasized as it significantly contributes to the nation's economy. However, in previous years, the South African construction industry has been viewed and criticised for its deprived performance and low success rates compared to other sectors (Ikuabe *et al*., 2022; Love *et al*., 2011). This results from the processes involved in project delivery that is at variance with the monotonous system attributed to other sectors, such as manufacturing (Ballard, 2012). Also, this is influenced by the use of outdated methods and techniques in delivering construction projects (Aghimien *et al*., 2021; Ikuabe *et al*., 2023). Consequently, it is believed that innovations and adaptations to new technologies can help attain a better delivery mode for construction projects. Kamara (2010) asserted that due to perennial problems like cost overrun, delay in completion, and poor quality delivery, the construction industry is an ideal candidate for a step change to abate the inefficiencies emanating from outdated methods. Other sectors have encountered improved delivery mandates resulting from implementing digital technologies. This is evident in the health, manufacturing, banking, and insurance sectors (Ikuabe *et al*., 2020). Hence, the call for using innovative technologies in the construction industry is highly encouraged. In construction processes, adopting technological innovations would immensely compensate for the deficiencies in human intelligence (Liu *et al.,* 2018).

The fourth industrial revolution (4IR) has served as a vehicle for applying emerging innovative technologies, aiding the promotion of digitalisation and overhauling the delivery processes in sectors such as manufacturing (Lu, 2017). This concept is applied to the construction industry and is termed *Construction 4.0* (BDC, 2016; Oesterreich and Teuteberg, 2016). The *Construction 4.0* idea is underpinned by the implementation of new technologies and the creation of smart construction sites and making work more efficient by doing construction work to be more accurately, reducing waste, cutting down on cost, timely completion of projects and creating safer construction sites (Edirisinghe, 2017). Other benefits of digitalising the processes involved in construction project delivery include accurate construction methods; better quality delivery; less physical work; better cost control and predictability; and easy clash detection and avoiding rework (Akinradewo *et al*., 2022; Adekunle *et al*., 2022; Akinshipe *et al*, 2022). However, Castagnino *et al*. (2016) stated that the construction industry is known for the slow adoption of innovations, hence, continuously subjected to the conventional challenges plaguing the industry due to the use of outdated techniques. These challenges are exacerbated due to factors such as the cost of implementation, maintenance cost, cyber security issues, the expense of employing requisite professionals, and resistance to adopting new technologies, amongst others (Oke *et al*., 2018; Dimick, 2014; El-Masaleh, 2007; Oladapo, 2007). Aside from these highlighted challenges, stakeholders' low level of awareness of various technological innovations still poses a great drawback to the adoption of digital technology in construction processes. Furthermore, Goodrum *et al*., (2010) noted that the awareness of a specific technological innovation does not guarantee its adoption; as a result, interrelated circumstantial events are needed to achieve a successful implementation. Therefore, it becomes imperative to have an assessment of construction stakeholders' current perception of the potential impact of the implementation of the use of innovative technologies in South Africa. Hence, this study is focused on unravelling professionals' viewpoints on imbibing construction 4.0 for the South African construction industry. The study will contribute significantly to the growing conversation of digital transformation within the construction industry with the specific mandate of focusing on South Africa.

2. Methodology

The study deployed a quantitative method of research using Gauteng province, South Africa, as the study area. The study's target population was construction professionals comprising of construction project managers, architects, quantity surveyors, and engineers. A quantitative survey approach to data collection was adopted using convenience sampling as a result of the peculiarity of the study and time constraints. Data was collected with the aid of a well-structured questionnaire which entailed two sections. The first section elicited the background information of respondents. In contrast, the second part dwelt on respondents' views on the impacts of the adoption of construction 4.0 in the delivery of construction projects. A 5-Likert scale was provided to ascertain the respondents' perception of the level of significance of the identified impacts of construction 4.0 in project delivery. A total of eighty-four questionnaires were distributed, while seventy-four were returned and deemed appropriate for analysis. Data analysis methods adopted for the study include mean item score, standard deviation, and one-sample *t*-test. The reliability of the questionnaire was ascertained using Cronbach's alpha which gave a value of 0.719, affirming the research instrument's reliability and validity (Tavakol and Dennick, 2011).

3. Findings and Discussion

3. 1 Background Information

The findings from the analysis conducted on the demographic information of the respondents for the study show that 46% of the total respondents are affiliated with contracting establishments. In comparison, 34% are associated with consulting firms and 20% work in government entities. Also, based on the years of working experience of the respondents, 70% have worked for 1-5 years, those having 6-10 years of working experience make up 20% of the total respondents, while 8% have a working experience of 11-15 years. Furthermore, based on the highest academic qualification of the respondents, 54% possess an honour's degree, 18% have a bachelor's degree, and 12% have a master's degree.

3.2 Impacts of Construction 4.0 Implementation

The study aims to evaluate the construction professionals' perception of the impact of construction 4.0 on the delivery of projects in South Africa. The review of extant literature yielded the identification of sixteen variables. These were presented to the target respondents of the study for rating based on their significance. The data retrieved from the survey were subjected to statistical analysis, including mean item score, standard deviation, and one-sample *t*-test. The study employed a one-sample *t*-test to ascertain the significance of the identified impacts of implementing construction 4.0 in South Africa. Consequently, a hypothesis was set for the study, which is: Null hypothesis states that an impact is insignificant if the mean value is less than or equal to the population mean (H_0: $U \leq U_0$); While the alternate hypothesis states that an impact is significant if the mean value is greater than the population mean (H_a: $U > U_0$). The study fixed the population mean (U_0) at 3.5 while the significance level was set at a 95% confidence level. The result from Table 1 indicates a two-tailed *p*-value indicating the significance of the identified impacts. All the identified impacts were proven to be significant, with all having a *p*-value of 0.000.

Table 1. One-Sample t-test

	Test Value = 3.0					
					95% Confidence Interval of the Difference	
Impacts	t	df	Sig. (2-tailed)	MD	Lower	Upper
Improved delivery time of projects	9.211	49	.000	1.08000	.8444	1.3156
Improved cost delivery of projects	4.911	49	.000	.74000	.4372	1.0428
Better quality delivery	8.791	49	.000	1.02000	.7868	1.2532
Less physical work	7.339	49	.000	.96000	.6971	1.2229
More accurate results	8.486	49	.000	1.08000	.8243	1.3357
Workers are more productive	6.416	49	.000	.86000	.5906	1.1294
Improved efficiency of the industry	7.012	49	.000	.96000	.6849	1.2351
Increased customer satisfaction	7.768	49	.000	1.04000	.7709	1.3091
Better waste management	7.000	49	.000	.90000	.6416	1.1584
Damage can be detected to infrastructure easily	5.505	49	.000	.66000	.4191	.9009
Can conduct safety inspection on site	7.399	49	.000	.98000	.7138	1.2462
Capturing data during claims management	5.308	49	.000	.74000	.4598	1.0202
Easy clash detection and avoiding rework	5.261	49	.000	.76000	.4697	1.0503
Reduces conflicts on projects	6.424	49	.000	.80000	.5497	1.0503
Improved collaboration owner/design firms during construction	5.261	49	.000	.76000	.4697	1.0503
Better cost control and predictability	7.054	49	.000	.92000	.6579	1.1821

Note: MD=Mean Difference

The findings presented in Table 2 show the ranking of the impacts of the implementation of construction 4.0 as perceived by construction professionals in South Africa. It is revealed that all the identified impacts have a mean value greater than 3.50, which is the threshold set for the study. Therefore, this affirms the postulation of the alternate hypothesis set for the study, which states that an impact is significant if the mean value is greater than the population mean (H_a: $U > U_0$). Also, it is shown that the outcome of the *p*-values of the impacts at a 95% confidence level is significant. The ranking of the impacts shows that improved time delivery and more accurate construction methods were ranked first with (*MIS=4.08, Sig.=0.000, R=1*) and (*MIS=4.08, Sig.=0.000, R1*) respectively, followed by increased customer satisfaction (*MIS=4.04, Sig.=0.000, R=3*), better quality delivery (*MIS=4.02, Sig.=0.000, R=4*), can conduct safety inspection at large site (*MIS=3.98, Sig.=0.000, R=5*), less physical work and improved efficiency of the industry were ranked sixth (*MIS=3.96, Sig.=0.000, R=6*) and (*MIS=3.96, Sig.=0.000, R=6*) respectively, better cost control and predictability (*MIS=3.92, Sig.=0.000, R=8*), better waste management (*MIS=3.90, Sig.=0.000, R=9*), workers are more productive (*MIS=3.86, Sig.=0.000, R=10*), reduces conflicts on projects (*MIS=3.80, Sig.=0.000, R=11*), easy clash detection and avoiding rework (*MIS=3.76, Sig.=0.000, R=12*), improved collaboration owner/design firms during construction (*MIS=3.76, Sig.=0.000, R=12*), improved cost delivery of projects (*MIS=3.74, Sig.=0.000, R=14*), capturing data during claims management (*MIS=3.74, Sig.=0.000, R=14*), and damage can be detected to infrastructure easily (*MIS=3.66, Sig.=0.000, R=16*).

Table 2. Impacts of the implementation of construction 4.0 on project delivery

Impacts	MIS	Std. Deviation	Sig. (2-tailed	Rank
Improved delivery time of projects	4.08	0.829	0.000	1
More accurate construction methods	4.08	0.899	0.000	1
Increased customer satisfaction	4.04	0.947	0.000	3
Better quality delivery	4.02	0.820	0.000	4
Can conduct safety inspection at large sites	3.98	0.937	0.000	5
Less physical work	3.96	0.925	0.000	6
Improved efficiency of the industry	3.96	0.968	0.000	6
Better cost control and predictability	3.92	0.922	0.000	8
Better waste management	3.90	0.909	0.000	9
Workers are more productive	3.86	0.948	0.000	10
Reduces conflicts on projects	3.80	0.880	0.000	11
Easy clash detection and avoiding rework	3.76	1.021	0.000	12
Improved collaboration owner/design firms during construction	3.76	1.021	0.000	12
Improved cost delivery of projects	3.74	1.065	0.000	14
Capturing data during claims management	3.74	0.986	0.000	14
Damage can be detected to infrastructure easily	3.66	0.848	0.000	16

3.3 Discussion of Findings

Findings show that implementing innovative technologies can improve delivery time and produce more accurate results for construction projects. Consequently, it is imperative that emerging technologies' diffusion is propagated to harness the glaring benefits from their espousal. This is corroborated by Oesterreich and Teuteberg (2016) by affirming that the significant strides presented by the uptake of digital technologies for construction project execution bring a shift from the conventional systems that are attributed to several bottlenecks. Also, Aghimien *et al*., (2018) noted that the emerging technologies presented by the 4IR have the potential to help reduce cost and time overrun as a result of more accurate construction methods. This is a pointer that time wasted on site unduly would be drastically cut down with the right and accurate methods deployed with the aid of digital technologies in construction processes facilitated by construction 4.0. Moreover, clients' needs are increasingly demanding and more complex; hence utilising digital technology in construction processes would aid in delivering clients' needs with minimal hitches. Castagnino *et al*. (2016) opined that the needs of construction project clients are significantly attained with the fusion of innovative technologies in construction processes. This results from improved process delivery and quality of work, cost optimisation, and timely completion of projects. Also, improvement in the working conditions on site is significantly guaranteed with the uptake of innovative technologies propelled by the 4IR (Hashim *et al*., 2013).

4. Conclusion

The study assessed construction professionals' viewpoints on the impact of the uptake of construction 4.0 within the South African construction industry. A review of the literature unravelled sixteen impacts and subsequently presented them to the target respondents of the study using a questionnaire for rating. Based on the study's findings, it is concluded that the significant impacts of the espousal of construction 4.0 are timely delivery of projects, improvement in the methods deployed for construction, customer satisfaction is met and better-quality delivery of construction projects. The construction industry is one of the cardinal sectors of the economy of any nation; hence, deploying digital technologies would result in an aggregate improvement of the industry, consequently, have a positive effect on the economy of any nation. The study proposes that digital technologies should be rapidly adopted and integrated into construction projects' delivery methods and processes. As evident from this study, the impact of its adoption is enormous. The propelling measures, such as its inclusion in the academic curriculum of higher institutions of learning and training of professionals of its usage, should be set in place to enable its embracement in the industry. Equally, stakeholders in the industry should imbibe the culture of changing from outdated conventional methods to accommodate recent innovations in technological participation in the construction industry. It is pertinent to state that the study was limited to Guateng Province, South Africa. It is proposed that future studies can be carried out in other Provinces in the country, as a more robust result would be achieved given that a larger study area would be covered.

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Recent Advances in 5D BIM Cost Control: A Novel Ontological Approach

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Abstract

Cost overruns have been a major source of concern to project clients and other project stakeholders for decades. Consequences of cost overruns include reduced profit margins for the contractor and numerous other issues for all stakeholders, including inefficient allocation of scarce resources, delays, contractual disputes, as well as project failure or abandonment. 5D Building information modelling is a viable solution to the aforementioned problems, but despite proliferation of 5D BIM applications, studies report slow application of these software in the construction industry. This has largely been due to issues relating to inadequate information, lack of standardization, and interoperability challenges. Interoperability issues can be addressed by merging BIM and ontology to improve cost management. However, research efforts merging BIM and ontology have focused more on the cost estimating and cost budgeting, with little research focusing on cost control. This paper proposes a conceptual framework for 5D BIM-based construction cost control that provides a formal description of entities and relationships based on ontology-based knowledge representation. The underlying principle of the framework is based on utilising 5D BIM technology in the process of cost planning, cashflow management and cost reporting to keep expenditure within a specified budget.

Keywords

Construction cost management, Cost control, BIM, Ontology

1. Introduction

The cost performance of a construction project is essential to determining its overall success (Ingle & Mahesh, 2022). However, cost overruns continue to be a prevalent problem in project management. Inadequate planning and scheduling, inaccuracy of time and cost estimation, erroneous quantity take-off (QTO) and bills of quantities, flawed cash flow projections for the project and the general deficiency in cost management (Memon et al., 2014; Rostami & Oduoza, 2017) are significant factors affecting cost performance. Interestingly, the use of the fifth dimension (5D) of building information modelling (BIM) emerges as a possible way to address these issues and is seen as a system that can improve cost management by making it more effective and efficient (Abdel-Hamid & Abdelhaleem, 2021; Mitchell, 2012). BIM has been widely applied in the construction industry due to its numerous advantages, which include a reduction in project execution time, construction cost reduction, the integration of tasks and professions, enhanced efficiency through clash identification and avoidance, and a reduction in risk (Abanda et al., 2020; Buhammood et al., 2020). Regarding cost management, 5D BIM incorporates cost element related to objects and object assemblies in the BIM model (Abanda et al., 2015). This can be accomplished either by incorporating cost information into the objects of the BIM model or by connecting to software tools for estimating in real-time (Stanley & Thurnell, 2014). This, in turn, makes it possible to extract exhaustive, accurate and precise data from the model, which can then be directly utilized for determining costs (Eastman et al., 2011).

Regardless of the potential and promises of BIM to improve construction processes, the application of BIM in cost management and specifically cost control is fraught with challenges (Kim & Grobler, 2013; Sepasgozar et al., 2022). There are some challenges that still need to be overcome such as lack of understanding BIM workflow, identification of essential information to be provided during the pre-contract and post-contract phases, identification of the methods for integrating as-built data into the designed models, lack of interoperability between BIM technology and cost management systems and absence of collaboration between stakeholders.

Recently, efforts by researchers (Abanda et al., 2013; Kebede et al., 2022; Pauwels et al., 2017; Ren et al., 2021; Sobhkhiz et al., 2021; Venugopal et al., 2015) demonstrated a possibility for enhancing several construction activities, including cost management, by merging BIM and Semantic Web to address the interoperability issues. The ontology used to explicitly express the knowledge and rules of a domain is essential to the semantic web (Abanda et al., 2017). BIM and ontology are widely studied areas, as BIM allows for standardized data and information for various calculations and analyses, while ontology aids in the representation and reuse of domain-specific concepts and reasoning rules (Ma & Liu, 2018). Ontology technology offers value to BIM by allowing for information integration and the ability to perform complicated queries across multiple information sources (Pauwels et al., 2017). As a result, the implementation of BIM, due to its ability to provide reasoning support, has proven advantageous in numerous domains of construction (Abanda et al., 2017; Abdullahi et al., 2019; Li et al., 2022; Ren et al., 2021; Zhou et al., 2023). More so, research have focused more on the cost estimating and cost budgeting, with little to no research focusing on cost control. This research therefore provides a novel approach for an ontological based framework for BIM-based construction cost control.

2. Literature Review

2.1 Overview of construction cost management

As stated in the Project Management Body of Knowledge (PMBoK) (Project Management Institute (PMI), 2016) "project cost management entails the planning, estimating, budgeting, financing, funding, managing, and controlling of costs in order for projects to be completed within budget". In the construction sector, cost management encompasses all cost-related activities. from project inception to effective occupancy and utilisation of a structure (Ashworth, 2013). Kelly and Male (2003) defined construction cost management as a service that focuses primarily on cost reduction or substitution. The term is also used to describe a multidisciplinary service which combines conventional quantity surveying techniques with systematic cost reduction or substitute processes. Prior to the commencement of construction, cost management prioritises cost planning and cost estimation processes. The purpose of the estimated cost is to generate a realistic and proper budget for the project while maximising the client's value for money (Lu et al., 2018). Cost planning seeks to arrive at an agreeable cost framework in the most economic manner, while considering aesthetics and technical feasibility (Royal Institution of Chartered Surveyors, 2013). After construction has commenced, the focus changes to cost control and making sure expenditures remain well within the predetermined budget and cost framework.

2.2 Building Information Modelling

BIM has transformed the construction industry away from conventional paper-based information management processes and toward automated information management methods fuelled by complex innovation, which brings various inclinations in terms of time, cost, and quality (Wu et al., 2014). By enabling users to input very specific property data into 3D building models, it has attracted a lot of attention in the AEC industry (Eastman et al., 2011). BIM has vast potential for automating the time-consuming tasks of quantity surveyors by providing a mechanism for direct, automated extraction of quantities from three-dimensional parametric digital models (Matthews, 2011). Several BIM-based estimating and quantity take-off applications have been created, including Navisworks, Assemble, CATO Suite, iTWO CostX, Solibri Model Checker, Vico Office, Innovaya Suite and Glodon etc. and have shown tremendous success (Moses & Hampton, 2017; Sepasgozar et al., 2022; Vigneault et al., 2020).

In BIM, the fifth dimension (5D) reflects the incorporation of the cost factor, which is acknowledged as a competitive cost management strategy for many firms (Smith, 2014). 5D BIM is gaining traction, and cost management organisations concentrating more on it as a result of its numerous benefits (Alrashed & Kantamaneni, 2018). Despite the many benefits of BIM, its adoption in the AEC industry is hindered by interoperability issues (Abanda et al., 2017; Abbasnejad & Moud, 2013; Azhar et al., 2008). BIM interoperability refers to the ability of BIM applications to share, transfer, collect, and handle data utilizing consistent standards and protocols (Grilo & Jardim-Goncalves, 2010). This is often cited as a major barrier to BIM adoption and can lead to significant costs during facility operation and maintenance (Pishdad-Bozorgi et al., 2018).

2.3 Semantic web and BIM

Since the emergence of BIM in the AEC industry, the number of areas in which it is being applied has grown substantially. Presently, BIM applications are not restricted to buildings alone; they also encompass bridges, tunnels, and roadways or any artefact in the built environment (Sobhkhiz et al., 2021). BIM has had a significant impact on the AEC sector, leading to the development and widespread use of BIM authoring and application tools like Autodesk Revit Architecture, Nemetschek Allplan, Autodesk Green Building Studio, Graphisoft ArchiCAD, Autodesk Revit Structure, Autodesk Navisworks, Vico Office Suite, Autodesk BIM 360, Autodesk FormIt (Farghaly, 2020; Nguyen et al., 2019). This developing trend has resulted in a paradigm shift in how industries define, customise, and utilise the semantics of geometry-intensive product models (Pauwels et al., 2017). Consequently, industry sectors and software developers have been increasingly interested in collecting and exchanging a building's "semantics." This interest encompasses not just design and construction, but also building engineering, HVAC design, facility management (FM), simulation, renovation, operational building management and demolition (Pauwels et al., 2017).

Multiple studies have investigated the potential use of semantic web technologies with BIM in the AEC industry and after several ontologies were proposed for BIM, more practical studies have emerged. For instance, by converting the EXPRESS IFC schema to OWL, Pauwels and Terkaj (2016) presented the ifcOWL ontology, which is an IFC-based ontology. This builds on the previous work of Beetz et al. (2009) that aimed to provide access to the IFC file format as RDF graphs, permitting it to connect to other RDF data sources. Additionally, Costa and Madrazo (2015) also contributed to this trend by creating an online catalogue for construction products that is compatible with BIM technology and allows access to acquire product information from within a BIM application by designers.

In construction safety domain, Wang and Boukamp (2011) created an ontological framework for outlining concepts and semantic connections linked to construction works, job stages, and risk origins with the goal of assisting in safety risk assessment. Similarly, Lu et al. (2015) created the construction safety checking ontology (CSCOntology) that includes five key concepts: "line of work," "task," "precursor," "hazard," and "solution."

In sustainable development, Jiang et al. (2018) in an effort to facilitate the green building evaluation processes proposed integrating BIM and semantic web. In a different study, Xiao et al. (2019) developed a semantic web and BIM-based technique for building energy management information retrieval. Similarly, a framework was created by Sobhkhiz et al. (2021) leveraging the capabilities of the semantic web to address the data management challenges of BIM-LCA (life cycle assessment) applications.

In cost management related domain, (Abanda et al., 2011) created an ontology for building labour cost estimation. Cheung et al. (2012) utilized a knowledge-based tool for defining and evaluating early-stage expenses called the low-impact design explorer to generate schematic BIM models. Lee et al. (2014) developed a method for inferring ontological structures to automate the search for the most appropriate work items for cost estimation, taking into account working conditions and efficiency. Liu et al. (2016) proposed an ontology-based semantic method for obtaining quantity take-off data from a BIM design model. Abanda et al. (2017) also examined the prospect of creating a cost estimating ontology based on the New Rules of Measurement (NRM) for use in tendering stages.

Similarly, Abdullahi et al. (2019) created an ontology for detailed measurement of building construction in Nigeria. Ren et al. (2021) presented an approach for retrieving information from the BIM environment with the ontological knowledge base to enhance automation and reasoning for more efficient value for money (VfM) assessments that facilitate decision-making.

In conclusion, various studies on ontology and BIM have been conducted in the construction industry during the past decade. Some studies explored the utilisation of ontologies for product modelling, while others focused on conceptualisation of construction domain knowledge. In cost management domain, which involve cost estimating, cost budgeting and cost control. The efforts range from development of ontologies to improve the accuracy of BIM-based quantity take-off/ cost estimation to automating reasoning in construction cost estimation. However, there seem to have been no studies specifically on the creation and utilization of ontology to automate the process of construction cost control. This research proposes a novel approach for an ontological based framework for BIM-based construction cost control.

3. Methodology

Taking a similar approach to applying design science research (DSR) approach to conceptual framework development (Barth et al., 2020; Nguyen et al., 2019), and following others such as Hevner et al. (2004), Vaishnavi and Kuechler (2004) and Weigand et al. (2021), this study adopted a DSR approach and three primary research methods are used to achieve its objectives. DSR is a methodology for conducting research that aims to create new, useful artifacts or systems (Vaishnavi & Kuechler, 2004). The goal of DSR in ontology development is to create a new ontology that is both useful and usable, and that can be applied in a specific domain or context. The ontology development process using DSR is characterized using a formal and structured methodology, rigorous evaluation and testing, and a focus on practical relevance and applicability.

To accomplish the objectives of this research, a comprehensive analysis of existing literature relevant to the topic was conducted. This literature review was focused specifically on the field of construction cost management, as well as two related areas of study: 5D BIM and semantic web technology. The data gathered for this study were extracted from several Royal Institute of Chartered Surveyors (RICS) guidance notes (BIM for cost managers: requirements from the BIM model (D. Smith et al., 2015), cost reporting (RICS, 2015), overview of a 5D BIM project (RICS, 2014), new rules of measurement 1: order of cost estimating and cost planning for capital building works (RICS, 2013), cashflow forecasting (RICS, 2011).

Based on literature review findings, BIM-based construction cost control process was established. Thereafter, ontology engineering was utilised to develop conceptual knowledge structure for BIM-based construction cost control. Ontological framework development involves creating a structured representation of a particular domain of knowledge, typically using formal logic or a controlled vocabulary (Singh & Anand, 2013; Slimani, 2015). This representation, known as an ontology, can be used to facilitate knowledge representation and reasoning tasks, such as information retrieval and semantic web applications. The development process typically includes tasks such as identifying the key concepts and relationships in the domain, defining the vocabulary and formal representation of the ontology, and validating the ontology through testing and evaluation (Noy & McGuinness, 2001; Suárez-Figueroa et al., 2011)

Finally, the developed ontological framework was validated. This is the process of ensuring that an ontology, or a formal representation of a set of concepts and their relationships, adheres to certain rules and principles. It includes checking for consistency, completeness, and accuracy of the ontology, as well as verifying that it conforms to established standards and guidelines for ontology development. The goal of ontology validation is to ensure that the ontology can be used effectively for knowledge representation and reasoning tasks. Various tools and techniques can be used for ontology validation (Baader et al., 2003; Brank et al., 2005; Gómez - Pérez, 2001), and many ontology development methodologies include evaluation as a part of the process. The frame of reference for ontology validation can include requirements specifications, competency questions, and real-world scenarios. This study utilised the requirements specifications as provided in the RICS guidance notes and semi structured questionnaire survey for the validation on the developed knowledge-based framework for BIM-based construction cost control.

4. Conceptual Ontological Framework for 5D BIM Cost Control

4.1 Concept of 5D BIM construction cost control

The paper presents an ontological framework for construction cost control using 5D BIM technology. The paper reviewed relevant studies about 5D BIM applications and ontology development for the research. As shown in Figure 1, the preparation of a 5D BIM model requires four primary processes. (1) BIM model development, (2) Quantity take-off (QTO), (3) Creating 4D BIM (i.e., integration of schedule information and QTO list), and (4) Creating 5D BIM (i.e., integration of cost information and schedule-loaded QTO list).

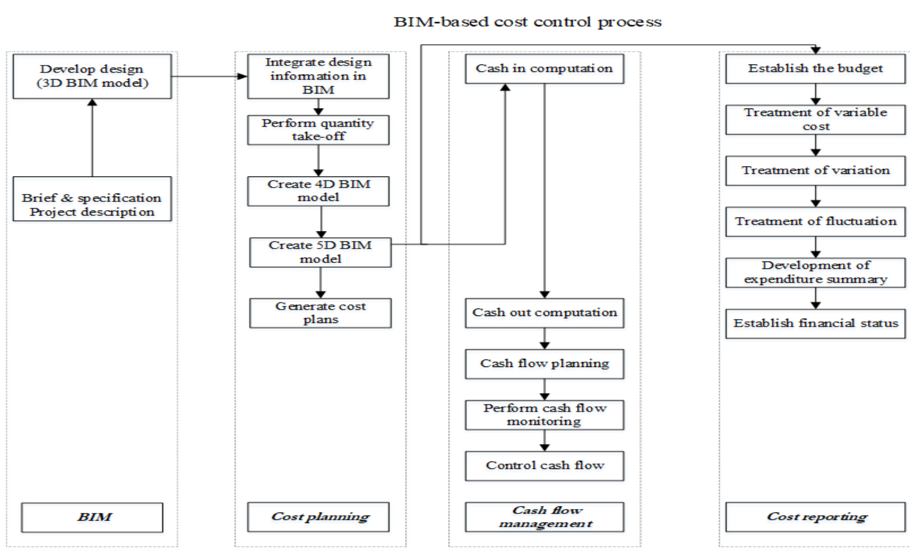

Figure 1: BIM-based construction cost control process.

During the cost planning phase, a building information model that comprises comprehensive geometric and semantic information can be incorporated into a 5D software system to produce a QTO list. By linking the QTO list with an external schedule database, a schedule-loaded QTO list is generated. By fusing this schedule-loaded QTO list with an external cost database, it is feasible to produce a cost-loaded project schedule, or cost-loaded timeline. This cost-loaded timeline file can then be imported into the 5D platform to generate a 5D BIM model, which can be utilized for conducting 5D simulations and creating cost plans.

In cashflow management phase, cash-in computation activity transforms the cost-schedule loaded information into project cash-in flows in the form of periodic payments, profits, retention amount and mobilization payment. This activity is governed by contractual conditions such as contract type, agreed-upon payment period, certification period, profit margin, retention percentage and period, and risk considerations associated with forecasting. Using 5D-BIM software tools such as Autodesk Navisworks and Causeway CATO suite, the computations are performed. The cash-out computation activity transforms the cost-schedule loaded information into cash-out flows for the project. It is governed by the various payment patterns agreed upon by contract parties and the forecasting risks affecting cash flows. Additionally, the computations are performed utilising 5D BIM software tools. The cashflow planning activity entails utilising several cash flow management techniques based on the organisation's cash flow policies to determine the most suitable strategy for planning the analysed cash flows. The cashflow monitoring activity determines the status and performance of the project's cash flow by comparing actual cash flow to projected cash flow. The final activity in the cashflow management process, control cashflows, leverages the output from the cashflow monitoring activity and current cashflow management strategies to correct the discovered deviations.

In cost reporting phase, which is the last phase of the construction cost control process. Using the established budget from the 5D BIM model, the first activity involves the treatment of variable costs like the provisional sums. The QS includes the full cost of each provisional sum in the outturn cost report at the outset of the construction contract. As work is completed and the costs are determined for each provisional sum, the quantity surveyor adjusts each provisional sum's outturn cost projection to reflect the actual costs incurred. The next step is to handle variations such as contract instructions. These must be valued according to the terms of the contract and included in the cost report. Once the value of a contract instruction has been agreed upon with the contractor, the cost report should reflect this. If the value has not been agreed upon, it should be identified separately in the cost report. If the contract allows for adjustments to the contract price due to fluctuations, the quantity surveyor must include the amount of the adjustment in the cost report, but only the amount of change that is applicable to the amount of the work completed to date, and the report should indicate that no provision for potential cost fluctuations has been made. Finally, the expenditure summary should be developed to provide the client with the financial status. In this way, the quantity surveyor enables the client to take steps to avoid cost increases or take advantage of any cost savings.

4.2 BIM-based cost control ontology

The ontology is designed to achieve standardisation and formalisation of BIM-based construction cost control domain knowledge in order to assist stakeholders in implementing highly efficient construction cost control (CCC). The concepts of this ontology cover construction cost control processes (cost planning, cashflow management, cost reporting), cost planning components (work breakdown structure, cost breakdown structure) cashflow management processes (cashflow forecasting, cashflow planning, cashflow monitoring & control), cost reporting components (treatment of variable cost, treatment of variations, treatment of fluctuations, expenditure summary). Concepts, sub concepts and relationships are depicted in the ontology as shown in the next sections. Concerning standards and technical manuals, five guidance notes are referenced in this research as summarized in Table 1.

Table 1. Knowledge Sources of CCC-Onto

Knowledge source	Type
BIM for cost managers: requirements from the BIM model	RICS guidance note
Cost reporting	RICS guidance note
Overview of a 5D BIM project	RICS information paper
New rules of measurement 1: order of cost estimating and cost planning for capital building works	RICS guidance note
Cashflow forecasting	RICS guidance note

4.3 Class and the class hierarchy

Cost planning

“Cost planning” is a subclass of “construction cost control” class, it comprises breaking down the building(s)' cost limit into specific into specific cost goals for each component of the building. It describes the methodology by which the design team wants to allocate the finances available among the constituent components of the building(s) and provides a framework for creating the design while keeping costs under control. “Cost planning” has other sub classes as “labour cost, material cost, plant and equipment cost, service cost, contingency cost, facility cost, cost of project insurance”. These components are provided as subclasses in the form of a "work breakdown structure (WBS)" and a "cost breakdown structure (CBS)," that can be used to organize the elements of construction work into packages for procurement. These subclasses are derived from the "5D BIM model".

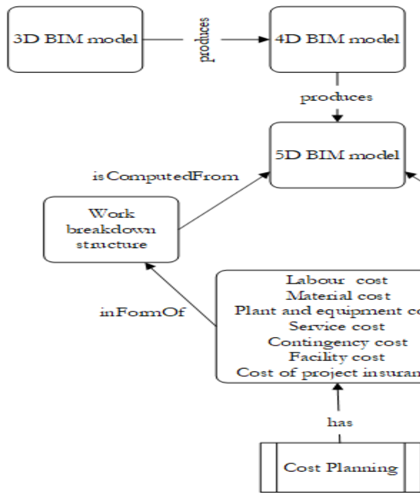

Figure 2: Cost planning class in the CCC-onto.

Cashflow management

“Cashflow management” is also a subclass of “construction cost control” class, it entails the subclasses of “cashflow forecasting”, “cashflow planning” and “cashflow monitoring and control”. It is described as a holistic process that involves the forecasting, planning, monitoring, and controlling of cash receipts and payments. “Cashflow forecasting” also has subclasses of “cash in” and “cash out”. “Cash in” class includes the computation of “profit, periodic payment mobilisation payment and retention payment” to arrive at a figure for the total cash receipts forecast. However, the “cash out” class includes the computation of “labour cost, materials cost, plants cost, subcontractors and suppliers’ payment, other fees” as forecasted payments.

In “cashflow planning” subclass, it entails either “frontend loading” or “backend loading”. “Frontend loading” is a strategy in which a bill's early items carry a larger margin than its later ones, while “backend loading” is a strategy in which the bill's latter items carry a higher margin than its earlier ones.

In cashflow monitoring and control” subclass, it is achieved by monitoring cash flow performance and applying corrective measures where deviations are spotted. It is done using variance and performance indices such as cost variance; schedule variance; cost performance index and schedule performance indices are computed to determine the status and performance of the project cash flow. “Cashflow performance” subclass is established by computing the “variance indices” based on “cost and schedule variance and “performance indices” based on “cost and schedule performance”.

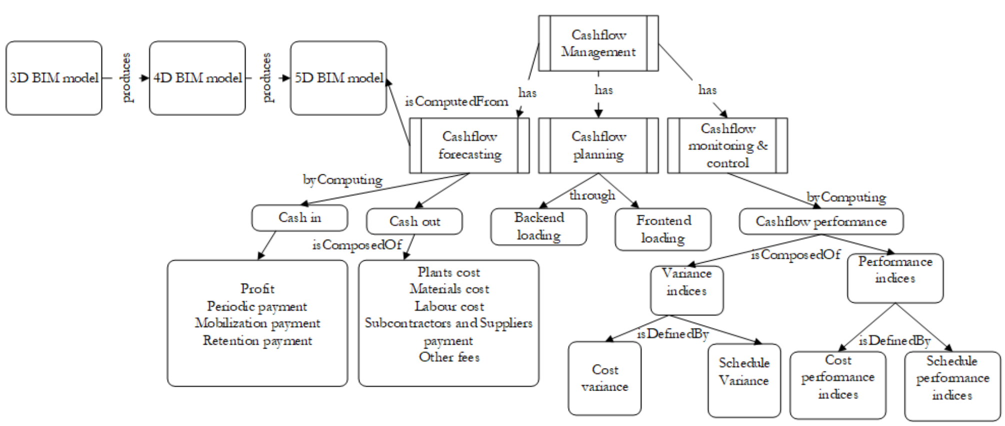

Figure 3: Cashflow management class in the CCC-onto.

Cost reporting

"Cost reporting" is also a subclass of "construction cost control" class. This entails:

all costs that have been incurred as of the report date and can be accurately valued according to the contract terms,

all costs that have been incurred as of the report date and can be reasonably estimated according to the contract terms,

an estimate of future costs that can be reasonably anticipated at the report date and estimated according to the contract terms, and necessary risk allowances that can be reasonably anticipated at the report date.

"Cost reporting" has subclasses of "treatment of variable cost, treatment of variations, treatment of fluctuations, expenditure summary and financial status".

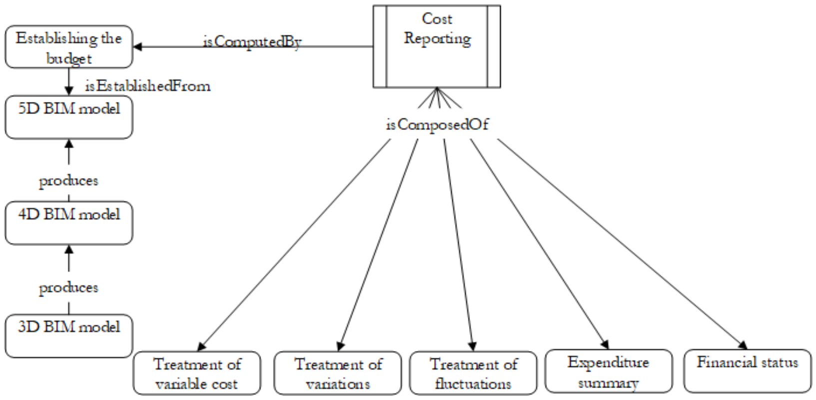

Figure 4: Cost reporting class in the CCC-onto.

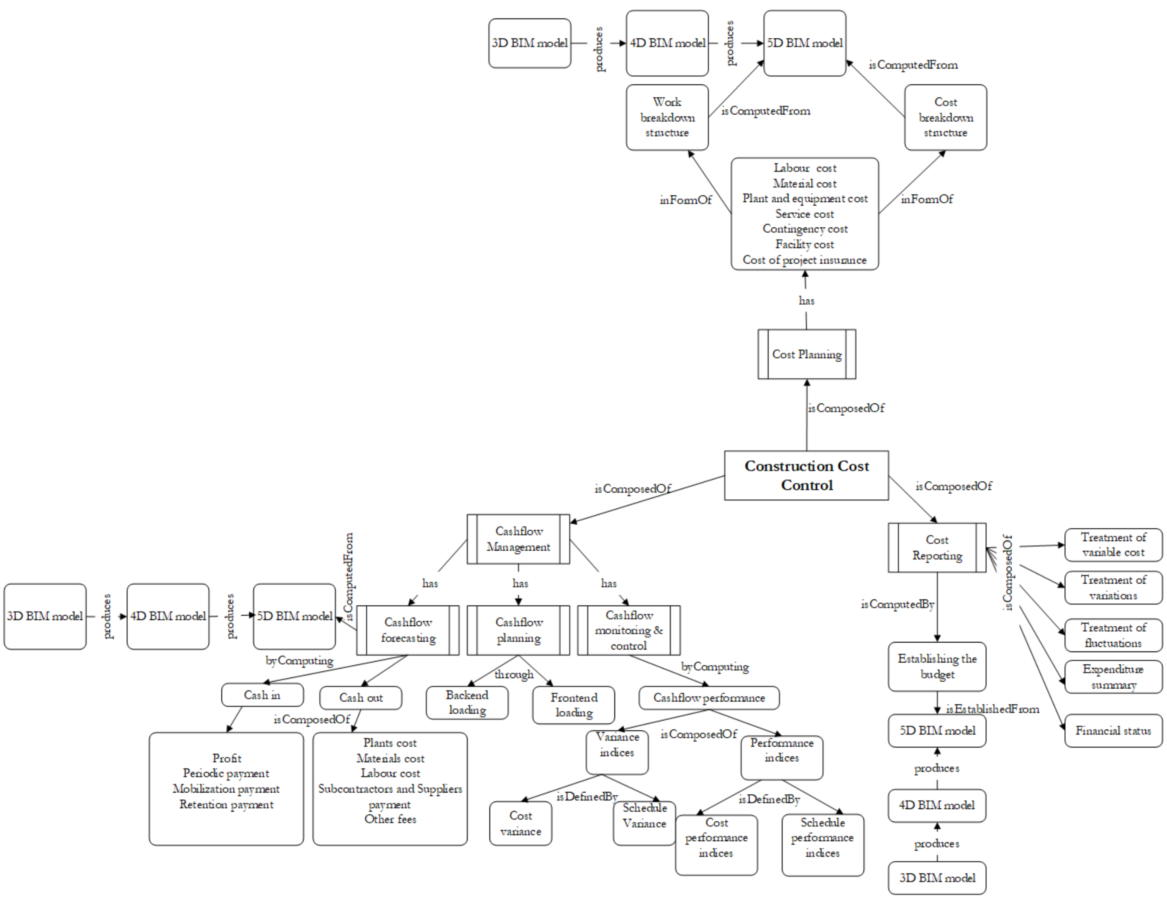

Figure 5: BIM-based CCC-onto.

4.4 Framework validation

The proposed framework as shown in Figure 5 was validated by utilising the requirements specifications as provided in the RICS guidance notes for each process of cost planning, cashflow management and cost reporting. This was adopted from (Lovrencic & Cubrilo, 2008) to determine the consistency, completeness, conciseness, expandability and sensitiveness of the developed knowledge-based framework. In addition, a semi-structured questionnaire survey was sent to the experts who had been involved in the previous ontology evaluation to evaluate the developed framework. As indicated in Table 2, the experts were required to respond to five questions using a 5-point Likert scale, where 1 represents disagreement and 5 complete agreement. Each question had an average score over 4, indicating that the constructed framework that integrates semantic web technology and BIM in construction cost control gained relatively high confirmation.

Table 2: Description analysis of questionnaire survey results

No.	Questions	Min	Max	SD	Avg.
1	The constructed framework facilitates the reuse of construction cost control knowledge	4	5	0.39	4.82
2	The constructed framework facilitates consistent and effective knowledge representation by formalizing the concepts and relationships of BIM-based construction cost control	4	5	0.49	4.65
3	The constructed framework promotes the integration of heterogeneous knowledge of processes in BIM-based construction cost control	3	5	0.64	4.18
4	The constructed framework provides computable information requirements for better semantic interoperability	4	5	0.44	4.76

5. Conclusion

This study began with a comprehensive literature review that led to an understanding of construction cost control and 5D BIM. Moreover, implementation obstacles for 5D BIM were identified and discussed. Interoperability, where there is no knowledge-based framework for BIM-based construction cost control, was a fundamental issue. The goal of the proposed conceptual ontological-based framework is to promote a shared comprehension of BIM-based construction cost control, establish the theoretical foundations of the concept and to provide practitioners with a thorough knowledge of the intrinsic structural aspects of construction cost control. To achieve this, the conceptual model should be designed in a way that is easily understandable for its users. When implemented correctly, the conceptual model should meet four essential goals (Kung & Soelvberg, 1986).

- Enhance understanding of the represented system.

The developed conceptual framework improves comprehension of the relationship and scope of BIM-based construction cost control by providing a comprehensive, integrated and thorough systematisation of the process.

- Support effective communication of contextual information among relevant stakeholders.

By utilising an ontological conceptual framework as a basis for BIM-based construction cost control, software developers can develop a common language and use the framework visually to facilitate the exchange of system information.

- Provide software developers with a frame of reference for to extracting system specifications.

This study provides software developers with a deep understanding of the underlying architecture of BIM-based construction cost control.

- System documentation for future reference and collaboration support

The proposed ontological framework assists practitioners and scholars organise and structure BIM-based construction cost control processes and communicate them to various stakeholders.

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Identification of the most serious barriers slowing down the process of the construction sector transformation towards the Construction 4.0 platform.

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Abstract
The extent to which the construction sector is lagging behind other sectors of the economy in terms of productivity, innovation uptake or competitiveness is at a critical level. There are now tools and ways to mitigate this negative trend. One of them is the Construction 4.0 technology and process platform derived from the concepts of the Fourth Industrial Revolution. Despite its existence for several years, it has certain barriers to its faster introduction into standard construction practice. The aim of this paper was to present an overview, based on a focused bibliographic search and own findings, of the efforts associated with the introduction of Construction 4.0. Among the most frequently cited and also as the most serious possible obstacles are financial difficulties associated with the cost of technology purchase and concerns about return on investment, personnel risks associated with the lack of professional staff to use the new technologies, personnel-ethical risks associated with the increase in unemployment, and process risks within supply chains. The findings will inform follow-up research studies to find solutions to accelerate the uptake of this innovation platform based on automation and digitalization in the construction sector.

Keywords
Construction 4.0, Transformation, Barriers, Innovation, Sustainability.

1. Introduction

Compared to previous industrial revolutions, it is the fourth one that is expected to become active almost worldwide thanks to globalization trends. The changes brought about by this revolution are being felt in almost all industries, but with varying degrees of intensity. The modification of Industry 4.0 into a Construction 4.0 (C4) concept or platform is expected to be a great help to the overall development of this traditional, and very slowly emerging industry (Adepoju & Aigbavboa, 2020; Zabidin et al., 2020). As the study by Yousif et al. (2022) puts it, the construction industry will not keep pace with other industries in productivity for an estimated 20 years.

The potential of digital transformation and wider use of automation in the sector can not only bring higher productivity, promote positive changes in the workforce profile, reduce costs, promote greater competitiveness and ensure more efficient use of resources to improve the environmental reputation of the industry (Wang & Guo, 2022; Kozlovska et al., 2021). Despite the claimed benefits, the exploration of new technologies and processes related to C4 is still in its infancy (Schönbeck et al., 2020). There are a number of review studies that describe the benefits of C4 or its individual components. However, very few address the barriers that prevent them from being more intensively integrated into construction processes. The aim of this study is to provide relevant information and insights into what are the current and expected barriers that, despite efforts to accelerate the C4 initiative, mean that we are still practically at the beginning.

1.1 The roles of Construction 4.0

Despite its gradual introduction from 2019 onwards, Construction 4.0 can be seen as a development trend or a developing area of research in the construction industry. Its idea is based on the convergence of trends and technologies embedded in the fourth industrial revolution. The aim is to transform the environment where they are applied. Theoretically, C4 encompasses several cutting-edge technologies and addresses a number of theoretical concepts that aim towards automation, integration, collaboration, innovation, optimization, decentralization and sustainability. Its primary goal is to innovate the physical environment, increase productivity, expand collaboration and optimize sustainability trends at the corporate and social level (Wang & Guo, 2022)

From an engineering perspective, C4 is the application of Industry 4.0 concepts in the sector, that is the application of digital technologies and processes adapted to the construction environment (Franco et al., 2020). It can be imagined as a new dimension or platform for the different processes associated with the design, planning, execution and management of construction projects and works. Among the specific tasks of C4, it is possible to include, for example, bridging innovation with established practices but implementing a process of convergence between clients and contractors.

Construction 4.0 technology	Categorization by Oesterreich & Teuteberg (2016)			Categorization by Sawhney et al.(2020)		
	Simulation and modelling	Smart Factory	Digitalization and virtualization	Design/digital layer		Construction/Physical Layer – Construction Site
				Digital Tools	Data	
Building Information Modelling/Management (BIM)	x				x	
Simulation	x					
AR/VR/MR	x			x		
Cyber-Physical Systems		x				
Radio-Frequency Identification		x				
Internet of Things		x				x
Automation		x				x
Prefabricated		x				
3D printing		x				x
Product-Lifecycle Management		x				
Robotics		x				x
Cloud solutions			x	x	x	
Mobile Computing			x			
Big Data			x			
Social Media			x			
Digitisation			x			
Laser Scanning				x		
Blockchain				x		
Drones				x		
Cybersecurity				x		
Big Data/Machine Learning/ Neural Networks			x	x		
Artificial Intelligence				x		
Sensor						x
Offsite Construction						x

Fig. 1. Overview of technologies taken for Construction 4.0

Figure 1 shows that in 2016, the possibilities of using Industry 4.0 for the needs of the construction industry were only gradually generated. By 2020, this list has expanded to include tools, based on technological development or client demand. It is to be expected that there will be no final list of C4 technologies. The above overview, e.g. does not include the approach that the Smart Contract, which is already currently taken as a permanent part of C4.

The key element of C4 and its best identifiable component is BIM. This successor of CAD systems is used by the participants of a construction investment project during the life cycle for the purpose of virtual modelling and information sharing (Tezel & Aziz, 2017). A combination of laser scanning, drones and video mapping is planned to be used for the needs of progress tracking on site. In order to increase process efficiency, productivity and safety, RFID is planned to be deployed which can track the location and movement of machines, materials and workers (Pärn & Edwards, 2017; Santos et al., 2017; Perrier et al., 2020). The use of GIS is planned to be used in combination with several technologies such as BIM or different sensors. The goal is information fusion (Perrier et al., 2020). Modelling systems include AR/VR/MR to enable digitization of the environment (Dallasega et al., 2018), machine learning will be used in real time data analysis (Whyte & Hartmann, 2017), robotics can be used for complicated technological tasks such as steel beam erection (Perrier et al., 2020). Manufacturing automation can contribute to increased work safety and reduced construction waste due to rationalisation of resource consumption. At the same time, its effect is expected in reducing human errors and greenhouse gas emissions, increasing productivity (ECSO, 2021; Begić, et al., 2022; Mêda et al. 2021) and in ensuring sustainable management of infrastructure (Karmakar & Delhi, 2021).

It is undeniable that C4's individual solutions and approaches will enable it to contribute to the transformation of the whole sector, taking into account better knowledge utilisation and increased efficiency. This is not only in the context of contributing to the 3 pillars of sustainability, but also towards eliminating the threats related to increasing costs or the continuous extension of the duration of work processes beyond the plan. At the same time, it is expected to contribute to improving the quality of construction work, improving the managerial control of construction and operational processes (Jemal et al., 2023), increasing new market opportunities, reorganizing business and delivery models, fostering an innovative environment and contributing to the reorganization of the relevant market (Nagy et al., 2021). C4 according to Garcia de Soto et al (2022) creates opportunities for value addition in terms of efficiency, security, growth and convenience, but at the same time supports new risks, vulnerabilities and threats associated with increasingly autonomous cyber-physical systems.

2. Methodology

The research method was a bibliographic review combined with bibliometric analysis. The study applies the PRISMA protocol approaches in its work with documents. According to Page et al. (2020), it includes a three-phase flow chart: phase 1: Identification, phase 2: Screening and phase 3: Included. The PRISMA technique is a set of considerations in conducting evidence-based systematic reviews and appears to be the most appropriate approach for the needs of our study. In addition, it is also used for research in the field of civil engineering, such as Alfadil et al. (2022) or Andersen et al. (2022).

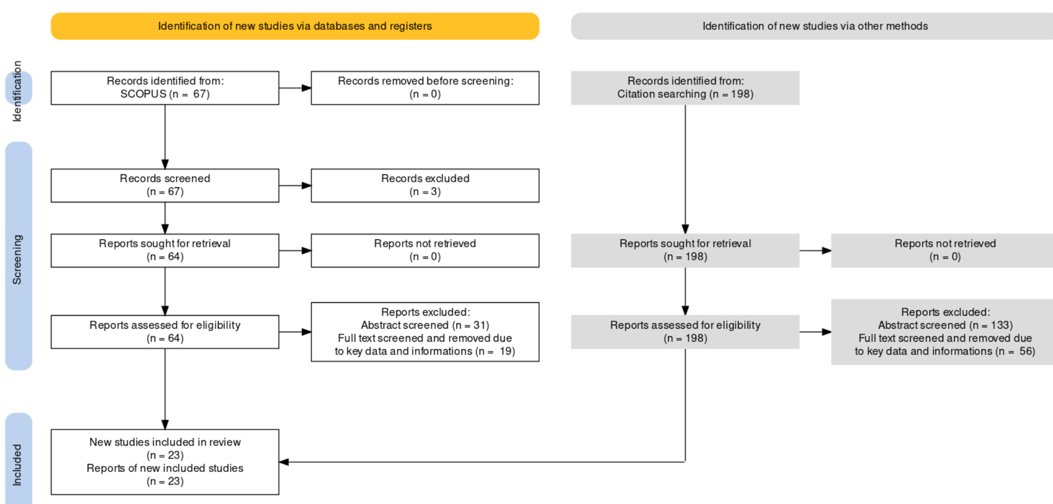

Fig. 2. PRISMA flow diagram

Initial searches were conducted in the SCOPUS database, which is more suitable for examining technically oriented studies. The algorithm was as follows *KEY (construction 4.0) AND (LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020)) AND (LIMIT-TO (EXACTKEYWORD , "Construction 4.0")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))* . A total of 67 publications were used for further investigation. The second search resulted in publications that cited these results but did not contain the keyword Construction 4.0. The algorithm was as follows Refined to: LIMIT-TO (LANGUAGE , *"English"*) AND (LIMIT-TO (SRCTYPE , *"j"*)) AND (EXCLUDE (EXACTKEYWORD , *"Construction 4.0"*)) AND (LIMIT-TO (SUBJAREA , *"ENGI"*)) . After further steps related to elimination based on abstract, publication availability, and overall suitability of the article for further analysis, 23 publications remained for our own research. At this point, it should be noted that the low number of remaining studies can be attributed to the orientation of the articles. These, in most cases, focus exclusively on the description of C4 technologies, without going even slightly into the problems associated with their application to real building practice. Thus, such papers are not suitable for the needs of our investigation.

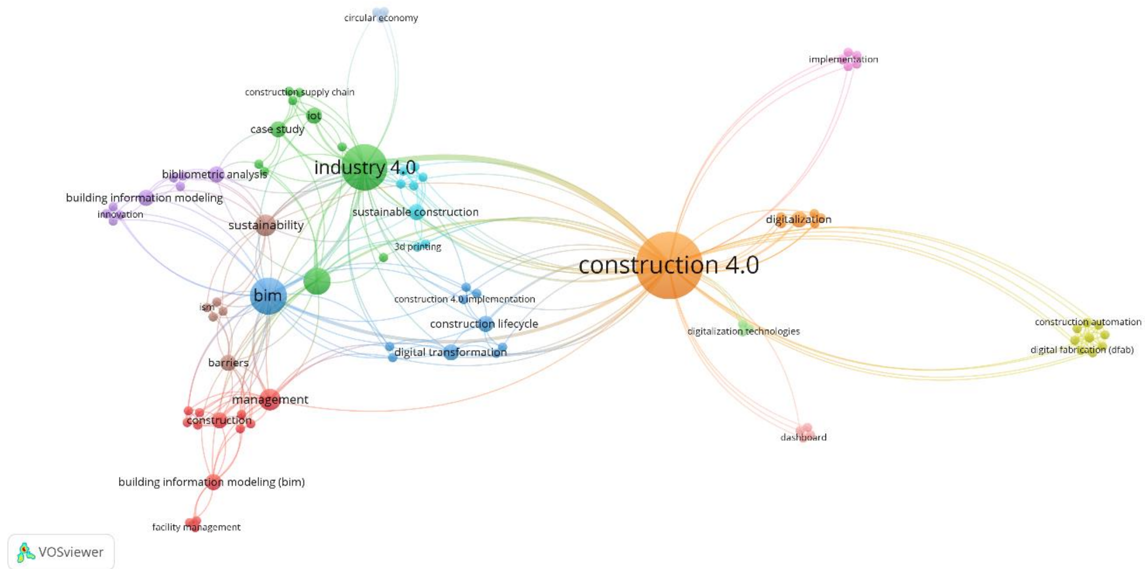

Fig. 3. VOSviewer keywords visualization

The publications that were worked with were also analyzed with VOSviewer software to generate and visualize the power of keywords (Fig.3). The size of the nodes indicates the frequency of occurrence. The curves between nodes represent their common occurrence in the same publication. The shorter the distance between two nodes, the greater the number of co-occurrences of two keywords.

3. Results

The results from the collective contributions clearly named a set of obstacles that stand in the way of a faster integration of C4 philosophy into application practice. The selection of the barriers was not easy, as these are not always individual definitions of the problems. Often the barriers are combined with each other, derived from the primary ones or are only complementary to the main barrier. Personnel concerns emerged as the clearest. They consist of two sub-categories. The first, according to Karmakar & Delhi (2021); Newman et al. (2020) & Wang & Guo (2022), is the social dimension associated with the loss of low-skilled workers through replacement by automation and digitalisation tools, and hence increasing unemployment rates in the sector. Especially in developing countries, this could pose a significant problem. As Yousif et al. (2022), Muñoz-La Rivera e al. (2021) and Al-Saeed et al. (2020) also state, it will certainly be a challenge for competent persons to strike a balance between limiting the rate of use of manpower and introducing technological innovation. In the context of the risks associated with a surplus of low-skilled workers, it is important to note that these concerns are justified if the right tools are not used. With the advent of C4, workers with varying degrees of digital skills will be needed. Also, a study by García de Soto et al. (2022) states that technological innovations in the construction industry, applied to improve productivity or safety, should not lead to an increase in unemployment and the transfer of workers to other sectors. The second part of the staffing barriers is the concern for skilled professional staff required for the deployment and use of C4 technology (Ibrahim et al., 2021; Onosen & Musonda, 2022; Jemal et al., 2023). The absence of these skills is a key issue (Adepoju & Aigbavboa, 2020; Jemal et al. 2022; Onosen & Musonda, 2022). The way to eliminate these barriers is to implement a system of retraining courses for already adapted workers or to bring new workers into the industry who already possess the skill. Despite the clear problems based on personnel, it is necessary to mention some specificities bringing some very valuable benefits. The increase in the complexity of the processes and the extent of dynamic changes associated with C4 in the different phases of the construction lifecycle is likely to increase the representation of women, cause an influx of IT professionals and allow for a higher representation of teleworking. All of this may increase the attractiveness of the sector as a whole. At the same time, it is anticipated that the combination of new C4-based processes and the modification of workers' skills will allow for a contribution to greater coordination and cooperation.

This would go some way to reducing the high degree of process fragmentation that the construction sector certainly has (Nagy et al., 2021; Karmakar & Delhi, 2021). Among the barriers cited many times is the financial aspect. This does not exclusively represent the cost of acquiring C4 technologies, but issues related to the cost of operating, servicing and repairing the equipment as well as the increased cost of expert servicing of C4 technologies also arise (Ibrahim et al., 2021; Onosen & Musonda, 2022; Jemal et al., 2023). As Larmakar & Delhi (2021) state, there are currently no reliable cost-benefit analyses that clearly present the benefits of individual technological and process innovations. This increases the level of risks present in e.g. pricing, especially in the case of construction contracts where the winner is determined based on the lowest price (Adepoju & Aigbavboa, 2020; Newman et al., 2021). The fact that business managers are responsible for efficient management and are only too reluctant to risk the possibility of investment mistakes associated with the purchase of technologies that are not essential to manufacturing operations also plays a role (Wang & Guo, 2022). It would certainly be worth considering going down the route of various innovation support schemes that could contribute to the transformation of construction technologies in firms.

Other barriers identified include those based on the specificities of the construction sector. The latter is also considered to be still highly bureaucratic according to Ariono et al. (2022), traditionalist according to Begić et al. (2022) and Adepoju & Aigbavboa (2020) and too volatile in terms of the presence of different types of risks. Wang & Guo (2022) point out the lack of strategies to implement C4 into common practice and Oke et al. (2022) state in their findings that despite the presentation of the concept of C4 based on digitalization and automation, specific mechanisms are named in a very general way, it is impossible to arrive at workable solutions and it is difficult to understand their real meaning. This barrier, according to Karmakar & Delhi (2021), is directly related to the lack of visionary vision of experts to spread awareness of the benefits offered and to motivate participants in the investment process to apply new technologies. The minimal professional and public demonstration of the capabilities of each technology at each stage of the construction life cycle, or the absence of the use of marketing tools, also plays a role (Hyarat et al., 2022). Related to this, as several studies by Oke et al. (2022), Ariono et al. (2022), Cao et al. (2022), and Onosen & Musonda (2022) indicate, is the need to conduct training, workshops, promote C4-oriented educational activities in high schools, and make universities centers for the development of advanced C4 platform technologies. The above is partly related to the poor communication of the expected roles of C4 towards the sustainability of the whole sector (Onososen & Musonda, 2022). As Franco et al. (2022) state, positive trends and research themes are present in C4. Nevertheless, the awareness of the importance of C4 to ensure the sustainability of the whole construction sector is insufficient. In their study, the author states that individual C4 technologies are not well connected to sustainability initiatives, with change efforts being individualistic in nature and a preference for mainly unilateral technical solutions rather than adopting holistic integrated management. In particular, the state and local governments, which are known to be one of the largest builders, should have a strategic role to support acceleration (Nagy et al., 2021). They can not only bring incentives for the use of C4 but also create pressure for wider deployment of C4 technologies in their own public projects (Hamza Momade et al., 2022; Newman et al., 2021).

Several barriers emerge in terms of planning and implementation of construction projects. A study by El Jazzar et al. (2021) states that there is a fundamental problem of only a very slow transition from a project-oriented mindset to a process-oriented approach. It also highlights the need to better identify at which stage of the construction lifecycle specific technologies can or should be deployed. Newman et al. (2021) and Menegon & da Silva Filho (2022) suggest that earlier phases such as projection, budgeting and scheduling are more suitable for digitalisation and can bring about the beginning of a change from dismissive attitudes. However, a high level of automation and digitisation in the design phase of construction according to (Begić et al., 2022) does not necessarily provide a benefit to the overall success of the project if the construction phase has extremely low or unapplied automation and digitisation. As stated by Hamza et al. (2022) the easiest way to implement the technologies used for construction and operation is in the planning phase, which could achieve cost savings in the initiation phase. From a construction project management perspective, the nature of the supply chain must also be mentioned as a barrier to the introduction of C4. This is mainly due to the high degree of individualism of interrelationships, not only between specific companies but also between projects. Following the construction process, some specific issues legitimately arise because of the possible application of C4 components in construction. As an example, various IoT elements that are permanently embedded in the structure of a building can be mentioned. These can be various monitoring systems for infrastructure buildings, where it is necessary to deal with their protection, management but also, for example, to provide data transmission to the evaluation environment. This implies the need to take a proactive approach to quality management, risk management and safety management during the operation and maintenance phase Perrier et al. (2022), Wang & Guo (2022) and Jemal et al. (2023), also in the context of guarantees related to the financial side.

Related to the above problems are corporate barriers. Pressures to modernise the whole sector are forcing businesses to innovate. The fundamental problem is that some processes were established long before the advent of digitalization and their transformation is both financially and time consuming, with no guarantee of return on investment (El Jazzar al., 2021). The size of enterprises is also an obstacle. In a market where small businesses and sole traders predominate, a high pace of change in the form of automation and digitalization cannot be expected. Despite the fact that larger enterprises would like to implement C4 trends, their production is often built precisely on the use of external capacities of smaller entities providing, for example, highly specialised services (Newman et al., 2021). At the same time, it is often the case that large enterprises often have outdated or inflexible business thinking and organisational structure. With the deployment of C4 in practice, the increase in costs associated with the operation, maintenance and repair of the technologies used must also be anticipated. At the same time, due to their complexity, it is necessary to have in-house staff or external service providers who can provide qualified service in the time available. As stated by Newman et al. (2021), the adoption of innovations can up to fundamentally change the previously used practices in workplaces. This can lead to a disruption of work culture, changes in work organisation as well as a deterioration in productivity. Despite the fact that some workers are open to new ideas, there are also those who are reluctant due to a lack of skills or motivation to learn new processes.

Legislative and methodological barriers also play a negative role. As Ariono et al. (2022) and Cao et al. (2022) point out, the absence of implementation procedures is a major problem in the adoption of technologies falling under C4 trends. An example is BIM. Despite their gradual diffusion, there is still a lack of universally accepted standards for their application, methods for the uniform generation of outputs and formats for data sharing between the different participants in the investment process. Enterprise risks that are slowing the uptake of C4 include issues related to the protection of sensitive data generated by the technologies and processes. Lack of attention to security issues can introduce threats to cyber security in enterprises. This issue is particularly serious from the perspective of protecting trade secrets in the context of data misuse during data sharing in the supply chain (Onososen & Musonda 2022) or from the perspective of legal protection of the inputs used (Hyarat et al., 2022). The reticence of companies is also supported by the poor possibilities, especially for the smallest companies, to use modern and secure ways for storing the generated data, which moreover must be quickly accessible (Osunsanmi et al., 2020; Jemal et al., 2023).

A barrier to wider adoption of C4 approaches is certainly the weak demand from customers (Onososen & Musonda, 2022). It is generally acknowledged that in the construction sector, the investor's primary goal is to satisfy their needs as quickly and cheaply as possible. However, they are already spending large amounts of money to meet any demands towards environmental or energy rules. The use of C4 technologies, whether in the construction phase or during operation, requires additional costs that have to be covered by someone. Hence the factor of low innovation culture in the construction industry causing slow transformation processes (Nagy et al., 2021).

4. Conclusions

Innovation in construction is a necessity. The last decade in the sector has been slow to build on previous modernisation rates and the extent of the lag cannot be ignored. It is necessary to realise that the construction sector is directly related to the economic and social development of society and is one of the sectors of the economy that have been assigned their roles in connection with ensuring sustainability. The advanced solutions presented by the Construction 4.0 platform, formed from Industry 4.0 approaches, may just be the ones to kick-start the long-demanded changes and bring about the necessary revolution. Research and expert studies published between 2020 and 2022, i.e. clearly demonstrate the usefulness of technological tools applicable in real practice. Despite this, we have a serious problem. This is the fact that we are still in the plane of presenting concepts, declaring the positive benefits of an increased share of digitisation and automation. There is a lack of fundamental knowledge associated with the real deployment of individual technologies in the form of demonstrative results. Also not available are detailed analyses assessing the financial side of putting C4 into practice, analysis of weaknesses, methodologies for managing identified risks. All this slows down the speed of commercialisation into wider construction practice. The identified barriers to acceleration in the deployment of individual C4 systems include primarily financial, staffing and process risks. This can be expanded to include shortcomings in the form of weak government support, the absence of a unified approach to introducing C4 into wider construction practice and very weak marketing. The solution could be to conduct additional studies that would provide answers to assess the process and financial efficiency of applying C4 technologies, for each phase of their life cycle. This would also improve the various financial analyses assessing the cost-effectiveness of introducing innovations. A summary of the strengths and weaknesses of specific technologies would also need to be drawn up, complemented by guidance and methodological documents related to their deployment, operation and maintenance. It goes without saying that C4 technologies bring their own characteristics of use and, with it, specific benefits and risks.

Building on the above, it is also important to be aware that the application of C4 may in some cases contradict some of the concepts associated with sustainability in the sector. Despite the assumption that C4 technologies should be conducive to these initiatives, in a secondary assessment some technologies may be shown to slow or negate the transition to greener or more energy efficient construction. They may also complicate the production process to such an extent that it becomes financially unviable. The integration of C4 components into sustainability processes should be one of the main research directions. Otherwise, there is a risk of disorientation of stakeholders. The future of the construction industry lies in the application of C4 technologies. However, it is mainly the role of the state, as both the creator of implementation policies and the largest investor, to ensure acceleration and reduce the gap between the speed of development of the different sectors of its own economy.

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Investigating Effectiveness of Construction Education in Collaborative Environments: Learning Within Discipline vs. Across Disciplines

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Abstract

Construction education has shifted to a more interdisciplinary pathway in the recent decades particularly due to constantly evolving environment in Architecture, Engineering, construction (AEC). It is essential for educators to understand this fundamental change and take actions to integrate skillsets that prepare students for such complex work environments. Effective communication and collaboration as important skillsets among disciplines is critical to success. As such, providing a learning environment to simulate teamwork could be significantly resourceful for students. In this study, we collected data from two groups of students in building construction science (BCS) and architecture (ARC) programs at Mississippi State University (MSU) who worked together to complete project(s). We particularly focused on aspects of learning that was influenced by peer-learning and compared the students' perceptions of learning within the same discipline and across disciplines. We also asked if students learned more from professors within their discipline or across disciplines as well as their preference for asking questions from professors within and across disciplines. Additionally, we asked about usefulness and perception of success with respect to peers from the same disciplines and across disciplines. Results indicated high levels of learning in ARC students from their BCS collaborators which can be justified since BCS students are better equipped, in that year level, with software and fabrication skills. Findings of this study are consistent with prior research indicating collaborative environments are helpful in promoting learning. The findings also support the notion that cross discipline collaboration can be at times more productive than same discipline.

Keywords

Construction, Education, Collaboration, Architecture, Effectiveness

1. Introduction

In the recent years, the significance of teamwork and collaboration has become more apparent to industry professionals given the interdisciplinary nature of AEC (Soetanto et al., 2012). As such, there is a shift required in academia to better equip students with tools and technics necessary for thriving in the industry when they graduate. Several studies looked at the feasibility of an educational framework that simulate a similar collaborative environment for students to learn how to work together on group projects (Becerik-Gerber et al., 2011; Oraee et al., 2019, 2021; Rokooei et al., 2022; Rokooei & Garshasby, n.d.). Many researchers within the AEC have focused on findings ways to better understand the student perception of collaboration and teamwork as well as enhancing the learning environment (Bozoglu, 2016; Rokooei & Garshasby, n.d.). Therefore, it is critical to investigate all dimensions of collaboration from the students' perspective so we can better implement features of teamwork that is conducive to student learning.

Collaboration by definition would happen when a group of independent stakeholders participate in an interactive process to solve a problem relying on shared norms and structures (Wood & Gray, 1991). A critical component of collaboration is negotiation between parties with mutual benefits. That being said, not all forms of collaboration is defined similarly due to different nature of the discipline that collaboration is taking place in (Bedwell et al., 2012; Thomson et al., 2009). Nonetheless, the principles of collaboration whether it is happening in the construction industry, or an educational setting remains similar and therefore, the skillsets required to participate in teamwork and collaboration remains similar as well.

Collaborative leaning environments also provide an opportunity for implementing problem-based learning (PBL). PBL focuses on student activities with the notion that students learn better when they experience and participate in learning first hand as opposed to a lecture based mode where there is a speaker and an audience (Soetanto et al., 2012). In MSU, two of the eight core classes are taught collaboratively between ARC and BCS programs via PBL mode. Students work alongside each other in completing a series of projects including a real size bench project through design-build to deliver to the client in the first collaborative studio. Students also work together on designing and developing a proposal for a commercial size building throughout the second collaborative studio. In this paper, we looked at the perception of teamwork and its impact on success and satisfaction levels in collaborative learning environments. The goal was to evaluate the effectiveness of these collaborative environments as well as the perception of students who are participating in these environments.

2. Methods

This paper relies on utilizing a survey questionnaire that was distributed to students in the BCS and ARC programs in Mississippi State University. IRB approval was received, and preliminary information was provided for the participants of the survey. 125 responses were collected (ARC: 34 and BCS:91). Both programs adopt a studio-based curriculum which allows for implementation of group projects and collaboration within and across disciplines. The survey entailed several sections aiming at collecting information on perception of students on learning. In this paper, we focused on aspects of the learning experience that was significantly impacted by collaborations.

We asked students about the degree to which they learned from their team members in their discipline as opposed to their collaborator major. We also asked the students about the degree they learned from their professors in their major as opposed to the professors in the collaborator major. Additionally, we asked the students about their preference in asking questions from their major professors versus the collaborator major. Moreover, we asked students to rate the quality of communication (timeliness, clear, polite, etc.) with their own major teammates versus their collaborator majors. Furthermore, we asked students to rate the usefulness and the degree to which they find the collaborative studio beneficial.

We asked students to vote on the importance of their team members (both own major and collaborate major) on the success of their projects/assignments. In addition, we asked them to rate the impact of several factors including regular feedback professors and teammates, complementary skills, diversity and so forth on the success of collaborative studio. Moreover, we asked them to vote their satisfaction with the performance of their team members (own major vs collaborator major). Finally, we asked the students to what degree they are willing to have another collaborative studio with their major collaborator versus any other major but their current collaborator. After the completion of data collection, all data entries were cleaned and checked for accuracy. A statistical model was developed to look at components of the inquiry and various statistical analyses were executed via SPSS.

3. Results

The data gathered from participants were analyzed on a "same or collaborator major" basis in this paper. Such categorization helped to clarify the perception of students toward different aspects of a collaborative environment. After the demographic part, the first section of questions explored perception of students about their peers. Participants were asked to rate the extent to which they learned from their peers while peers were from their own major or the collaborative major. Figures 1 shows the percentage of each level rated by both majors, using a Likert scale. As shown, 50% of architecture reported a high or very high level (29% and 21%) of learning from architecture students in their collaborative environment, while this number for BCS students was 53% (46% and 7%).

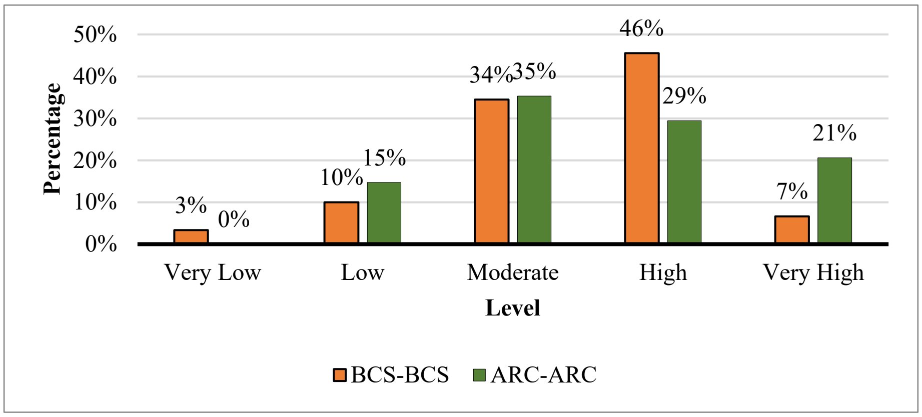

Figure 1: Learning from own major teammates in the collaborative studio

Similarly, participants rated their learning from their collaborative major peers. The percentage of each level is shown in Table 2. As shown in the table, 76% of architecture rated their learning from BCS students as high or very high (55% + 21%) while 17% BCS students expressed a similar opinion about their learning from architecture students (13% + 4%).

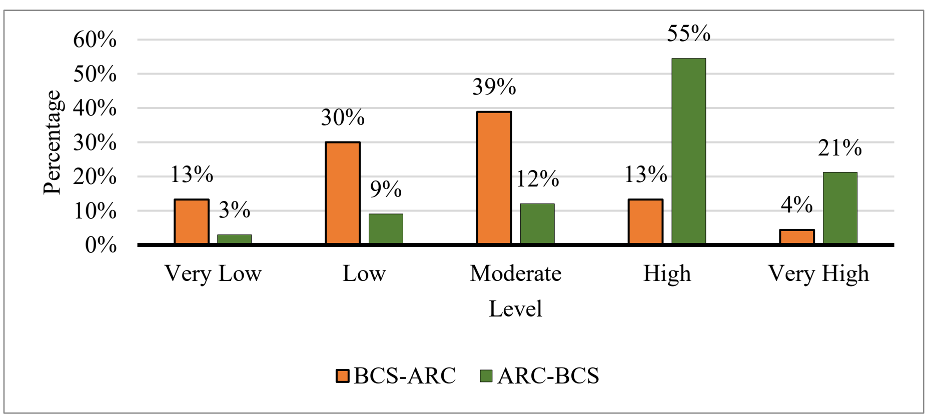

Figure 2: Learning from collaborator major teammates in the collaborative studio

In the next question, students were asked to rate their willingness to ask the questions or discuss the points with own major instructors in the collaborative environment. Figures 3 and 4 show the percentage of each Likert level for students' willingness to interact with their own major instructors (Figure 3) and their collaborative major instructors (Figure 4).

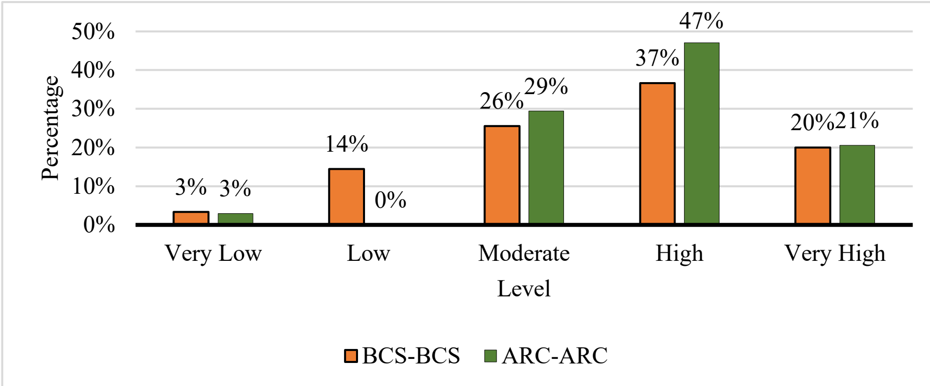

Figure 3: Willingness to interact with own major instructors

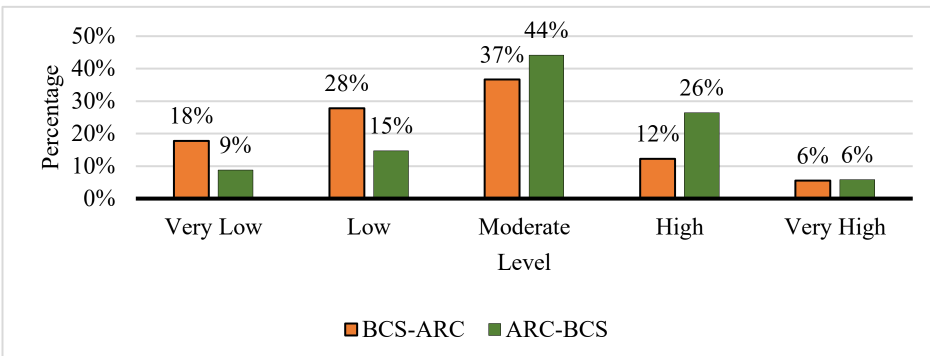

Figure 4: Willingness to interact with collaborative major instructors

In the next section, students evaluated the quality of their communication with their own or collaborative major students. Both majors highlighted the high quality of the communication with their own major peers (architecture: 35% as high and 26% as very high vs BCS:42% as high and 16% as very high). A similar situation was reported as the quality of communication in working with collaborative major teammates (architecture: 15% as high and 15% as very high vs BCS:33% as high and 4% as very high).

In the next section, students rated the extent to which they believed the collaborative environment would have been useful if they had it with their own major students (Figure 5) or with their collaborative major students (Figure 6). In other words, students were asked to rate the usefulness of educational environment in single major or double major structure. A five-level Likert scale was used to quantify the evaluations.

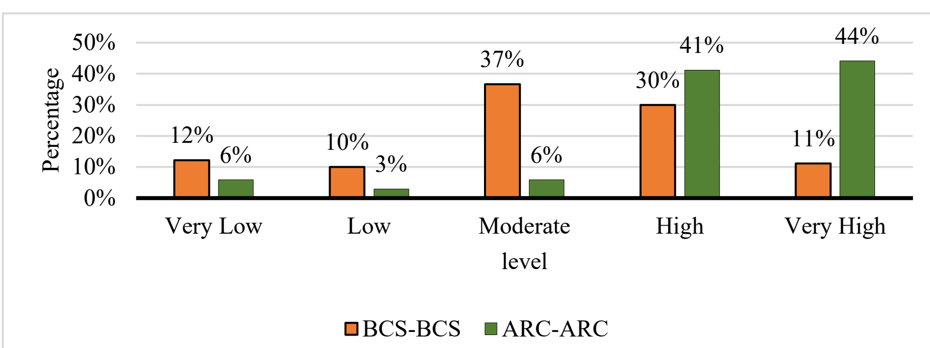

Figure 5: Usefulness of collaborative studio with own major teammates

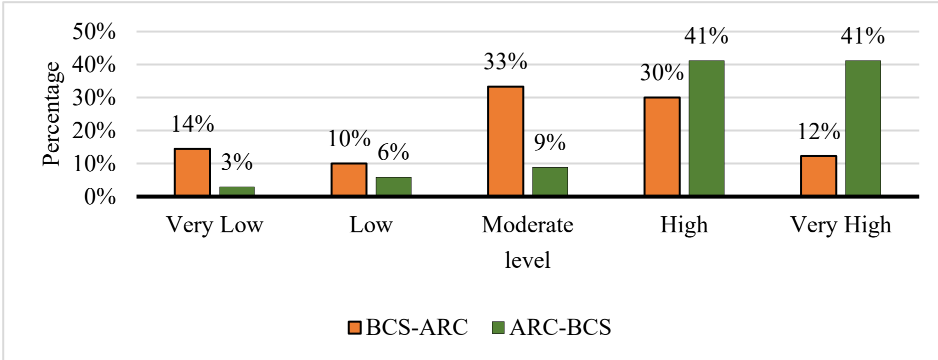

Figure 6: Usefulness of collaborative studio with collaborative major teammates

Also, students were asked to rate the impact of a series of pre-defined factors on the success of collaborative educational environments. Factors included regular feedback by professors, teammates, colocation, diversity, effective communication, trusting relationships, mutual benefits, commitment to participate, and shared understanding. A five-level Likert scale was used to quantify the perceived impact. The average score of each factor (out of 5), categorized by major, is shown in Figure 7.

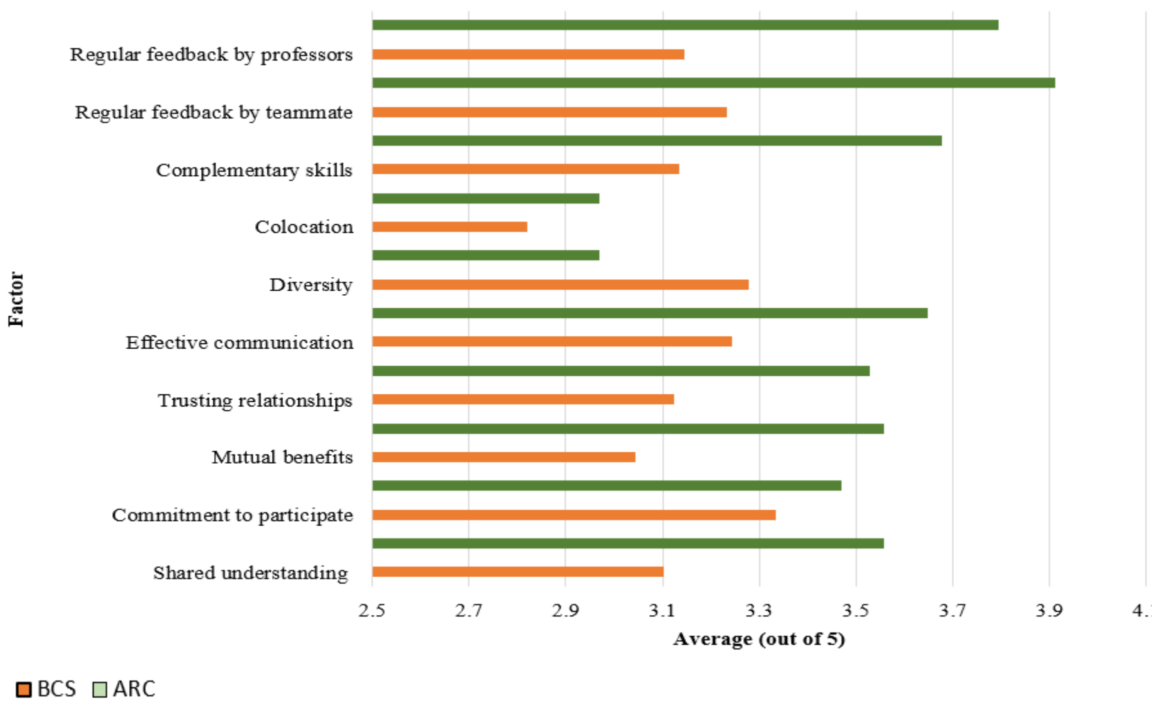

Figure 7: Impact of factors on the success of the collaborative educational environment

4. Discussion

The perception of students about different aspects of their educational environment plays a major role in their learning process. Such perceptions become highlighted when students participate in a collaborative environment in which they attend classes which are not necessarily housed in their department, interact with students from other majors, learn from instructors whose major, emphasis, and approaches may be different. The current study explored the perception of construction and architecture students in collaborative environment with a heavy load of project-based learning activities. The educational structure of the courses required students to constantly interact with each other, rely on their peers' work to continue, and be responsible for the entire team output.

This paper shows a portion of data through the lens of major. Both groups showed similar perceptions about a number of items, however, different viewpoints in some other areas were notable as well. Architecture students reported a higher level of learning from their BCS peers, as shown in Figure 2. They also expressed a higher level of willingness for interacting with the other side (Figure 4). Another notable point is the factors impacting the success of collaborative environment rated by BCS and architecture. In all areas, except diversity, the average score was higher in the architecture group. It is noteworthy that female students comprise about 50% of students in architecture, while this number in BCS is 8%.

5. Conclusion

This paper aimed at investigating the effectiveness of collaborative learning environments with a particular attention to cross-disciplinary versus single disciplinary paradigms in two collaborative studios between ARC and BCS programs at Mississippi State University. The findings supported the idea that students perceive learning more effective when they engage in collaborative projects. There were areas in which, students from each major shared slightly different votes but the overall analyses supported the effectiveness of cross-disciplinary learning environments.

It is important to note that students who participated in this study had different levels of training and backgrounds that may have impacted their level of preparedness to collaborate and therefore influence their perception of effectiveness of collaboration and collaborative studio in general. Additionally, in our study, BCS students were better equipped with technical skills in modeling and fabrication which was essential to completion of projects. This may shed light on nuances in responses to questions regarding learning from collaborative major in ARC students since the BCS students are better equipped to complete the projects.

As educators, we will need to constantly look for ways to prepare students for future workforce development. The results of this study along with the existing literature supports the notion that simulating teamwork and collaboration in educational setting can provide an effective platform for addressing learning objectives in construction education. Moreover, findings of this study support the idea that cross-discipline collaboration has been more effective and productive than single-discipline collaboration. More investigation is needed to better understand how collaboration in construction education may yield similar results under different circumstances. Finally, understanding the students' perceptions is integral to implementing efficient mediums in delivering optimal construction educational content.

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Factors Contributing to Success: Self-Performing Framing and Drywall Scopes on a Construction Project

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Abstract
Completing construction projects successfully on time and on budget is extremely critical for survival of construction firms. Not every construction firm can do this, and several researchers identified various factors that contribute to the success of the projects. However, more construction firms have started opting to self-perform certain scopes of the projects as they see it as an opportunity to improve safety, quality, and profits of the projects. In this changing trend, it is important to understand factors that contribute to the success of self-perform scopes of a construction project and there is currently no literature available. This research bridges that gap by performing qualitative interviews with case study construction project personnel from both general contractor and self-perform teams. The results identified that effect communication between general contractor and self-perform teams, effective planning and scheduling from general contractor, dedicated supervision efforts from self-perform team, hand-on experience of general contractor superintendent on self-perform trades, and trustworthy relationship between the general contractor and self-perform teams play an important role in the success of self-perform scopes of the projects. Understanding self-perform project success factors helps contracts in gaining new insights to achieve improved efficiencies and profits on construction projects.

Keywords
Self-Perform Scope, Construction Success Factors, Effective Communication, Construction Planning and Scheduling, Contractor Relationship

1. Introduction

This case study was requested by the general contractor self-performing the framing and drywall hanging and finish because the project had been successful. Since not all projects self-performing framing and drywall in the division had been as successful, the company wanted to identify best practices. This project was a negotiated project with the general contractor's project fee set at 2.25%. Since it is rare that the fee can be increased on a project with a Cost Plus with GMP (Guaranteed Maximum Price), the general contractor wanted to self-perform the framing and drywall. Since the owner and the general contractor had a long-standing, trusting relationship, the owner did not ask for competing framing and drywall bids. At the end of the project, the general contractor's total project fee was 3.25%, which is a 44% increase over the original fee. This fee increase was directly attributable to the self-performed framing and drywall scope. This study identified the best practices that facilitated project success as identified by the project participants. The results of this study are not generalizable to any other project or population because the sample is small, and these data are limited to this case study only.

1.1 Research Aim and Objectives

The purpose of this research is to identify factors and best practices that contribute to the success of self-perform scope of construction projects by adopting a case study interview methodology from a particular renovation construction project in the mid-west region. Specific attention was placed on the aspects of the project team (both general contractors' team and self-perform team) and actions or practices of the general contractors and self-performing team that are crucial in the success of a self-perform aspects of the construction projects scope.

2. Literature Review

In a dynamic industry like construction, contractors strive to understand the different factors contributing to the project success. Project success is defined as minimizing risks, completing on budget, on time and making profits for the contractor. Generally, in the construction industry, the general contractor's hire subcontractors or trade partners to do all the trade work. Reasons why general contractors choose to use specialized subcontractors (Mincks & Johnston, 2017, p. 260):

- Specialized labor for construction tasks: Skilled craftspeople trained in the specific assembly perform the task correctly, enhancing quality of the installation and completing the task efficiently, minimizing invested man-hours.
- Lower cost for subcontract work: As the labor for the subcontractor is specialized and only a narrow range of work is accomplished, subcontractor costs are generally less.
- Reduced risk for the general contractor: Several areas of risk are reduced by subcontracting work rather than accomplishing the work with the general contractor's own direct hire forces. The risk of labor productivity is shifted to the subcontractor.

Reducing risk has been a primary factor in the general contractors' decisions to subcontract most of the work on a project. The various aspects of risk include productivity and/or cost control, from the estimate to the project's completion; lack of expertise in specialized areas, control of potential liquidated damages; cash flow; poor quality from lack of experience or having the right craftspeople; and cleanup, warranties, and other aspects of the general conditions (Mincks & Johnston, 2017).

For these reasons, some commercial buildings projects are "100% subcontracted" (Mincks & Johnston, 2017, p. 4). It seems that the trend of general contractors subcontracting 100% of the work is changing. FMI Corporation, a construction industry research and consulting firm since 1956 stated that "In a 2015 study published by FMI, 45% of survey respondent across the construction industry indicated that they plan to increase the amount of work they self-perform in the future, with another 20% responding that they are considering expanding their capabilities" (Esler & Newcombe, 2016, p. 16). The FMI study went on to explain that "increasing the amount of self-performed work comes with its own risks – including hiring, training and retaining talent – but firms see the benefit of increased control over the project's schedule and quality" (Esler & Newcombe, 2016, p. 16). Several studies in the past have researched project success factors for general contractors, however, there is no existing literature available regarding the success factors that contribute to the success of self-perform work of the general contractors. This study interviews project participants to understand the factors that contributed to the success of self-perform scope on one project project for an anonymous technology company in the mid-west region.

2.1 Self-Perform Work

Self-performing work means the lead general contractor uses in-house skilled labor and equipment for certain constructions scope such as concrete, electrical, plumbing, framing or carpentry. Often, self-performing particular scopes of work can benefit a project. More importantly, self-perform capabilities add value for all stakeholders (Brasfield & Gorrie, 2022). Research shows that self-performing construction is on the rise as it benefits contractors and owners in several ways such as increasing safety, quality, efficiency while also minimizing the risks and uncertainties on the job site (Jouvenal, 2020). Self-perform also improves the profitability of general contractors, and the owners can get the project built for a lesser cost relatively (Belvins, 2022). Although it is understood that self-perform projects have several benefits both to general contractors and owner, some general contractors prefer not to self-perform work (Belvins, 2022) owing to lack of understanding related to factors that can contribute to the success of self-perform scope of the project. Currently, there are no studies that identified factors influencing the success of self-perform scope of a construction project.

2.2 Construction Project Success Factors

One of the widely accepted definitions for construction project success is completing the project on time, under budget, and according to specifications (Alzahrani & Emsley 2013). To achieve construction project success, Duy Nguyen et al. (2004) identified that having (1) a capable project manager; (2) a multidisciplinary/skilled project team; (3) dedication to the project; and (4) the availability of resources is extremely crucial. Some of the construction project success factors identified in the literature are provided below in Table 1.

Table 1. Project Success Factors from literature review

Factors	References
Effective communication between stakeholders	Yang et al. (2010)
Effective planning and scheduling	Doloi et al. (2012), Kog, Loh (2012)
Effective procurement and project management	Chan et al. (2004)
Project manager capabilities and commitment	Kog, Loh (2012), Chan et al. (2004)
Effective site management and commitment to project	Doloi et al. (2012)

3. Research Methodology

“A case study is an exploration of a bounded system or a case (or multiple cases) over time through detailed, in-depth data collection involving multiple sources of information rich in context” (Creswell, 1998, p. 61). This case study was conducted at the request of executive leadership for a nationwide general contractor. The objective was to understand and synthesize the factors or best practices that seemed to lead to self-perform project success. The authors developed interview questions and privately interviewed project participants on a major renovation project for an anonymous technology company in the mid-west region. The self-perform scope considered for this research is framing and drywall work. According to the general contractor, this is one the most successful self-perform projects (framing and drywall) they completed as the self-performing scope of this project was finishing within budget, within schedule, and making consistent profit. Therefore, the executive leadership at the company wanted to identify the best practices and factors that contributed to the success of self-perform scope of this this specific project. Therefore, the authors developed a case study interview protocol according to DiCicco-Bloom and Crabtree's (2006) recommendations to include experience questions and knowledge questions. Seven project participants were identified, interviewed separately, and the recorded interviews were transcribed by a third-party transcription service. Table 2 shows the details of all participants.

Table 2. Participant Information

Participant	Experience(yrs.)	Role/Position
Participant 1	32	GC superintendent
Participant 2	7	Self-perform superintendent
Participant 3	16	GC project manager
Participant 4	7	GC assistant project manager
Participant 5	12	Self-perform project manager
Participant 6	16	Division project controls manager
Participant 7	19	Self-perform foreman

The participants were interviewed in the general contractor's regional office or at a neutral site away from construction projects to avoid distractions. The open-ended case study interviews were semi-structured, and the purpose of using this approach was to initiate each interview with a set of open-ended questions that would lead to a thoughtful discussion while providing the flexibility to pursue appropriate follow-up probing questions. The interview questions mainly focused on demographics, key contributing factors to self-perform project success, individual's impact on the self-perform project success, and challenges to successful completion of self-perform scopes in a project as shown in Table 3.

The interview transcript data were coded using open, axial and selective coding to allow themes (best practices) to emerge. Patton (2002) states, "Discovery and verification mean moving back and forth between induction and deduction, between experience and reflection on experience, and between greater and lesser degrees of naturalistic inquiry" (p. 67). A constant comparative approach (Bogdan & Biklen, 2003) was used after each interview was coded to "look for key issues, recurrent events, or activities in the data that become categories of focus" (p. 67). These categories of focus became central in subsequent interviews to check for consistency in the themes that emerged.

Table 3. Open-Ended Interview Questionnaire

Demographics:
1) Please tell me your name, how long you've been with the company, and your position on the subject project.
2) Please describe your role on this project and how it changed as the project progressed.
Key Contributing Factors to Project Success
1) As you reflect on the main job and self-perform teams, describe the key contributing factors for project success on this project?
Individuals' Impact on Project Success
1) As you think about all the GC jobs and self-perform personnel involved with the subject project, identify the top three individuals (and their traits specific to project success) that have contributed to project success and try to be specific as you explain why.
Challenges to the self-perform project success
1) Corporate executives are committed to self-performing various scopes on construction projects in all Regions. Describe the challenges that you've identified in the company doing more self-performed scope on projects.
2) Were these challenges experienced on this construction project and how were they overcome?

While seven interviews is a small sample, according to Mason (2010), the size of the sample in qualitative studies is irrelevant because the value of the study is based on the quality of data. The primary reason for recruiting these seven participants was their experience, expertise, and willingness to participate in the study. Implementing such a strategy, according to Simms and Rogers (2006), increases the richness of data due to the commitment of the interviewees.

4. Results & Discussion

Based on the responses of the interview participants in this research, the success factor's themes identified are organized into the following categories, namely,

1. Communication
2. Scheduling/Planning
3. Self-perform supervision
4. Hands on experience of GC super
5. Relationship between GC team and self-perform team

4.1 Communication

Communication is one of the most important factors affecting the construction project success. This study identified that efficient, transparent and open communication related to estimates, budget and work planning between general contractor team and self-perform team are crucial for a self-perform project success. Participant 3, the general contractor's project manager said,

> At the start of the self-perform scope, we had a very good communication with drywall estimator to understand the project costs from their side and co-relate budgets from our side working through a lot of the details and things and the expectations of how things were going to go. And then, we had a great communication with self-perform project engineer and superintendent regarding on time procurement and building. Both teams always had honest and transparent communication regarding project issues. This helped both teams understand budgets and schedules clearly, and work accordingly to meet the project goals,

indicating that clear communication about project goals, issues, and planning helped self-perform team achieve success. Echoing the same, participant 5, self-perform project manager said,

> The GC side and the self-perform side discussed earlier, got on the same page early, learned what's in our estimate so that both sides can be bought in on the scope of work. I think that was very valuable, and I think that that's something that we should do going forward.

Adding to this, participant 7, self-perform foreman mentioned,

> We communicated so much with GC superintendent and knew exactly where we were going the next day. Also, we have a board. We have maps on the wall that told the crew where they're going through the next five days. So, we plan ahead for the time for five days,

indicating that planning properly and effectively communicating that to the team is critical in the success of a self-perform project scope.

4.2 Scheduling/Planning

This case study identified that creation of a clear schedule that breaks down every tiny task of the project by the GC team and communicating the same to self-perform team so that they can breakdown their budgets appropriately and updating the schedule regularly as the project goes is extremely important for self-perform project success. This is evidenced by participant 5, self-perform project manager as he said,

> Once we were awarded the scope of work, I was breaking down the quantities and the budgets. I had the budget broken out by the GC Superintendent's schedule. Because his schedule was so detailed, I was able to extract quantities in each area and know what the budget amount was for each area, which was further helping the project control process, and that helped us stay on budget and time,

indicating the importance of a detailed schedule for self-perform project success. Furthermore, participant 2, self-perform assistant superintendent said, "The detailed schedule helped us identify key activities and their durations clearly, making the self-perform team's job easier to discuss how many crew members are needed", confirming that detailed schedule is important. He further added that,

> Our [self-perform] foreman was able to read the schedule, dissect that schedule for his activities only or activities that precede him or activities that come after him in order to build a three to six-week look- ahead schedule for himself to ensure other trades are not affected,

indicating the need to train foremen on reading and understanding schedules to ensure self-perform project success. The participant 7, drywall self-perform foreman supported this saying, "Detailed schedule helped us a lot. every morning we'd get together, and we'd talk about the job and make sure we attacked the critical part, make sure we're not holding anybody up, like electricians and MEP", confirming the importance of detailed schedule. Adding to this, participant 4, general contractor assistant project manager said,

> Our [general contractor's] super always updated schedules as the project goes and issues come up, reworked on the schedule to accommodate what was going on. He was constantly learning schedule related updates from self-perform team, and reworking schedules based on their needs and challenges. Having our superintendent knowledgeable and staying on top of what the self-perform team is doing helped us achieve the success,

he further added, "The self-perform assistant superintendent did an amazing managing the day-to-day progress and looking ahead and coordinating issues between the GC team and the self-perform craft so that they can be productive and complete on schedule" indicating that general contractor superintendent's and self-perform superintendents scheduling knowledge and their enthusiasm to address schedule related challenges helps improving the performance of self-perform scope for a general contractor. Overall, this indicates that scheduling knowledge and the ability to update schedules, communicate that with all team members, and enthusiasm to solve schedule related challenges by superintendents and foreman helps completing self-performing scopes on time.

4.3 Self-Perform Supervision

This study identified that diligent supervision efforts from the self-perform team and respective responsible leadership from general contractor's team make a huge difference in the success of self-perform scope of the construction project. Participant 1, GC superintendent mentioned,

> The contribution of self-perform superintendents is enormous in project success. The self-perform superintendent of this project made sure his men were set up the right way, they always had material looking forward weeks and months in advance, extremely attentive to the schedule, worked hard to make sure that things worked, made sure the supply chain kept coming. All of this contributed to the success.

Adding to this, participant 5, self-perform project manager said, "Site supervision was critical to the success of this project. For example, making sure timecards were right so we can track the production well, tracking quantities and hours accurately, etc. helped staying on track of this project". In addition, participant 2, self-perform assistant superintendent mentioned,

> My biggest goal was to get to be as good a companion or sidekick or however it needed to be with [the drywall foreman] to support him over the course of the beginning of the project. I was looking at schedule and manpower, talking materials with [the drywall foreman]. I [sat] in on sub meetings and coordinating with the superintendents for the electrician. I was coordinating with the superintendents for HVAC, MEPs, and then I was also running productivity. I was there walking the job 8 to 10 hours every day with [the drywall foreman], asking questions, getting those questions out to the GC team.

This indicates that sincere supervision efforts from self-perform team are crucial in the success of self-perform scope success.

4.4 Hands-On Experience of GC Superintendents

This research identified that having GC superintendents with hands-on experience in self-perform trades is valuable for success of the projects. Participant 3, self-perform project manager opined,

> I think because of the GC Superintendent's background in framing and drywall, he was able to understand the scope of work pretty detailed, and the fact that he was able to break out his schedules in a way that we could actually track against.

Adding to this, participant 4, GC assistant project manager said,

> I think that [the GC Superintendent] is one of the greatest driving factors in the project overall, and especially his efforts on the self-perform. One big thing is he has a heavy carpentry background himself and so he was able to walk the site and say, 'Hey, you guys are supposed to be 50 percent done, I'd say you're about 25 percent done,' and he would send that to the self-perform team. They would check their productivity and most of the time he was right on the money. So, having that knowledge really helped.

This indicates that hiring superintendents that have hand-on experience in the trades that the general contractors would like to self-perform is valuable for the project success. By doing this, the hand-on experience the GC superintendents have will help them understand the challenges of self-perform teams and support them accordingly.

4.5 Relationship between GC team and self-perform team

This research identified that establishing a trustworthy relationship between both the GC team and self-perform team and having an attitude of one team are important factors that influences both teams towards success. Confirming this, participant 5, self-perform project manager mentioned, “I think it was just the one team mentality from everybody that helped the project. We would not have been as successful as we were without the GC side wanting to make us successful”. Further he added, “There was never anybody taking advantage of anybody. We had trust built. So, it never was contentious. It was always the GC side helping us and us trying to help the GC side by getting ahead” with materials procurement. Participant 7, foreman opined that the GC team always supported them and mentioned, [The GC Project Manager] would come once a week for the meetings, "and he'd always come to me and say, 'Well, is there anything I can do for you?' and those kinds of questions. And, I mean, to me that's support right there.” This indicated different ways, the relationship was strengthened with the teams by establishing trust. This indicates that establishing early on in the project and maintaining the same throughout the project duration helps both teams and thereby the success of the project. Table 4 shows a summary of all responses from the participants.

Table 4. Summary of Participant Responses

Success Factors	**Participant**	**Response**
Communication	Participant 3	At the start of the self-perform scope, we had a very good communication with drywall estimator to understand the project costs from their side and co-relate budgets from our side working through a lot of the details and things and the expectations of how things were going to go. And then, we had a great communication with self-perform project engineer and superintendent regarding on time procurement and building. Both teams always had honest and transparent communication regarding project issues. This helped both teams understand budgets and schedules clearly, and work accordingly to meet the project goals
	Participant 5	The GC side and the self-perform side discussed earlier, got on the same page early, learned what's in our estimate so that both sides can be bought in on the scope of work. I think that was very valuable, and I think that that's something that we should do going forward
	Participant 7	We communicated so much with GC superintendent and knew exactly where we were going the next day. Also, we have a board. We have maps on the wall that told the crew where they're going through the next five days. So, we plan ahead for the time for five days
Scheduling/Planning	Participant 5	Once we were awarded the scope of work, I was breaking down the quantities and the budgets. I had the budget broken out by the GC Superintendent's schedule. Because his schedule was so detailed, I was able to extract quantities in each area and know what the budget amount was for each area, which was further helping the project control process, and that helped us stay on budget and time

	Participant 2	Our [self-perform] foreman was able to read the schedule, dissect that schedule for his activities only or activities that precede him or activities that come after him in order to build a three to six-week look ahead schedule for himself to ensure other trades are not affected
	Participant 7	Our [general contractor's] super always updated schedules as the project goes and issues come up, reworked on the schedule to accommodate what was going on. He was constantly learning schedule related updates from self-perform team, and reworking schedules based on their needs and challenges. Having our superintendent knowledgeable and staying on top of what the self-perform team is doing helped us achieve the success
Self-perform supervision	Participant 1	The contribution of self-perform superintendents is enormous in project success. The self-perform superintendent of this project made sure his men were set up the right way, they always had material looking forward weeks and months in advance, extremely attentive to the schedule, worked hard to make sure that things worked, made sure the supply chain kept coming. All of this contributed to the success
	Participant 5	My biggest goal was to get to be as good a companion or sidekick or however it needed to be with [the drywall foreman] to support him over the course of the beginning of the project. I was looking at schedule and manpower, talking materials with [the drywall foreman]. I [sat] in on sub meetings and coordinating with the superintendents for the electrician. I was coordinating with the superintendents for HVAC, MEPs, and then I was also running productivity. I was there walking the job 8 to 10 hours every day with [the drywall foreman], asking questions, getting those questions out to the GC team
Hands on experience of GC super	Participant 3	I think because of the GC Superintendent's background in framing and drywall, he was able to understand the scope of work pretty detailed, and the fact that he was able to break out his schedules in a way that we could actually track against
	Participant 4	I think that [the GC Superintendent] is one of the greatest driving factors in the project overall, and especially his efforts on the self-perform. One big thing is he has a heavy carpentry background himself and so he was able to walk the site and say, 'Hey, you guys are supposed to be 50 percent done, I'd say you're about 25 percent done,' and he would send that to the self-perform team. They would check their productivity and most of the time he was right on the money. So, having that knowledge really helped

Relationship between GC team and self-perform team	Participant 5	I think it was just the one team mentality from everybody that helped the project. We would not have been as successful as we were without the GC side wanting to make us successful
	Participant 7	[The GC Project Manager] would come once a week for the meetings, "and he'd always come to me and say, 'Well, is there anything I can do for you?' and those kinds of questions. And, I mean, to me that's support right there

5. Conclusion

The objective of this study was to identify project success factors and best practices for success of a self-perform scope of work for a general contractor through a case study of technology company renovation project in the Midwest region. The study provided a list of factors that influence the success of self-perform scope of work that includes effective communication, efficient planning and project scheduling, self-perform supervision, hands-on experience of general contractor superintendents in self-perform trades, and establishing trustworthy relationship between both general contractor and self-perform teams. The factors identified in this study are similar to those factors for overall project success identified in other studies, however there is a difference in how these factors play out between the general contractor and self-performing teams as both teams belong to the same company with one goal of project and company success. The limitations of this study include a small sample size and that all participants were from the same company and same project. Future research is recommended to explore conducting more interviews with project teams that handle self-perform scopes, and also extend a mixed-methods study to collect data from a large set of project teams from across the U.S. regarding the self-perform project success factors and how those factors influence each other. This study contributes to the body of knowledge by identifying attributes of general contractor teams and self-perform teams and factors that contribute to the success of self-perform scope of construction projects. This information can be used by construction firms doing self-perform scopes to effectively complete their projects within time and budget.

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Implementation of remote working in the Latin-American construction industry

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Abstract

The topic of remote working in the construction industry has gained traction in recent academic literature as a consequence of technological innovation and the COVID-19 pandemic. The purpose of this research is to study how the Latin-American construction industry is adapting to the practise of teleworking by exploring the drivers, strategies and challenges behind its implementation.

An inductive approach was taken to conduct and analyse 20 semi-structured interviews from employees and employers from Latin-American companies related to the construction sector. The impressions collected were grouped and discussed by themes, contrasting the findings with the existing literature and arriving to the following conclusions:

- The COVID-19 pandemic has been the primary driver behind the implementation of telework in the Latin-American construction industry.
- Remote working was implemented in the Latin-American construction sector primarily through the use of communication and data transmission tools, as well as employee training and support.
- Latin-American construction companies are not using the equipment and software available to perform remote work to their maximum capacity.
- Few companies in the Latin-American construction sector are applying change management principles to implement teleworking conditions.
- The main challenges for implementing remote working in the Latin-American construction industry are social and mental obstacles, as well as technological limitations.

Future research could use this investigation as support to find potential solutions to overcome the current barriers to telework implementation in Latin-America, as well as how to improve remote cooperation with the help of technology and the implied cost-benefit.

Keywords

Remote work, Telework, Construction industry, COVID-19, Latin-America

1. Introduction

Remote working is a topic that has received much attention lately due to advancements in technology, as well as the onset of the COVID-19 pandemic (Slavković et al., 2021); (Felstead & Reuschke, 2020).

For the sake of this research, remote working is defined as a mode of labour in which the subjects involved are located in geographically distant places, usually out of the office environment (Janene-Nelson & Sutherland, 2020) Although the incorporation of new trends in the construction sector is rather slow, some studies have been done regarding remote work in this field.

In the construction business, the advantages of remote working might be linked to lower overhead expenses related to office activities such as electricity and water costs, waste disposal, etcetera, since these are eliminated when the employees are working from home (Ogunnusi et al., 2022) Some other benefits of remote working are the reduction of car emissions, flexible schedule and work environment, as well as time saving in commuting (Orzeł & Wolniak, 2022)

Even though owners and employees of project offices recognize the advantages of remote working, there are some major obstacles for the adoption of telework in the construction industry. Executing significant changes in project offices can be challenging due to the busy nature of the business, lack of necessary digital skills among employees, and the preference of clients for physical interaction with the design and construction team (Orzeł & Wolniak, 2022)

The cost of implementation is another barrier for many companies, even though using affordable equipment could make these technologies accessible to more people (Moore & Gheisari, 2019). Aside from this, there are concerns related to remote collaboration using these devices, as they might be susceptible to privacy and security issues when connected to the network (Wang et al., 2021).

An additional challenge faced by remote collaboration is the human psyche, as interaction can become more difficult in a remote setting (Manko, 2021). Change management could be a useful instrument to implement this new working method effectively, but it is necessary to gather more data from the field to identify the specific issues affecting the implementation of telework in the construction industry. It is notable to mention the small amount of information regarding remote collaboration among construction workers in developing countries. The aim of this paper is to explore the way remote working has been recently conducted in the Latin American construction industry in order to understand how it could be used more efficiently.

2. Background

According to (Hai-Jew, 2014), there are seven factors that are driving the implementation of remote work worldwide:

- Enhanced technologies at a lower cost.
- Access to a diverse labour pool.
- Opposition to relocation from employees.
- Less need for permanent office space.
- Requirement for business continuity in case of force majeure.
- Demand of flexibility in work schedule and place from personnel.
- Increase in productivity markers from remote workers.

These factors are similar to those presented by (Soroui, 2021), who reported rental cost, territorial coverage, retention and expansion of employees as main drivers of telework implementation. In addition, the COVID 19 pandemic and its associated social isolation policies hastened the adoption of this kind of labour. According to a survey conducted in May 2020, 35% of USA workforce was labouring from home because of the coronavirus (U.S. Bureau Of Labor Statistics, 2022). In the UK, the percentage of employees saying they only worked from home increased from 5.7% in February 2020 to 43.1% in April 2020 (Felstead & Reuschke, 2020).

2.1 Benefits and challenges of remote working

According to literature, remote work provides an array of benefits from an organizational perspective since the satisfaction reported by employees when allowed to choose their work environment enhances productivity markers for the company (Popovici & Lavinia Popovici, 2020). Corporations also view telework as a cost-cutting technique because employees who don't spend all their time in the office use less utilities, office space, and other resources (Golden, 2009), making it a 'win-win' situation in which employers profit from a more efficient labour force more cost effectively, and workers gain a superior work-life balance (Felstead & Henseke, 2017).

As working remotely became more common, not only the advantages but also the downsides of it have been gradually revealed. (Popovici & Lavinia Popovici, 2020) found in several studies that telework agreements could affect the work-life balance, performance and health of an individual, which can indirectly impact the company. To avoid this, the implementation of telework requires changes in scheduling, behavior, and physical arrangements in the home environment. Nevertheless, these might not be enough, and teleworkers could lose the restoratives qualities of their homes due to the practice of doing mental effort related to work in their free time (Hartig et al., 2007).

Finally, the dispersion of office activities, unavoidable result of teleworking, raises new issues related to cybersecurity. To prepare for any infringement, all job-related devices should have strong and modern protection software to secure working infrastructure from any cyber-related threat (Mihailović et al., 2021).

2.2 Remote working in the construction industry

Telework has increased significantly, yet some vocations and industries use it more frequently than others. For example, in computer-related industries teleworking is practically the norm nowadays, while jobs like manufacturing and some service positions have seen very little growth in this area. Given the physical separation of the working team, there is a strong reliance upon technology to interact while working remotely (Golden, 2009) a factor that has not been explored in the construction industry as much as in other sectors.

According to (Jallow et al., 2021), the COVID outbreak affected the management and operation teams more than any other group in the construction industry, since it was harder to lead the team remotely, as well as complete work that required physical interaction with the construction site. The least affected were the design teams since their work usually does not need physical interaction and they could communicate easily through digital mediums. These technologies allow faster and more organized data transfer ((Burton et al., 2021). Nonetheless, risks related to the digitization of the design and construction process, such as the loss of information and data duplication act as barriers to the adoption of digital processes (Orzeł & Wolniak, 2022).

2.3 Remote working in Latin America

Some nations were better equipped than others to keep their economy stable while adhering to social distance. As stated in a study measuring the impact of remote work in thirty countries, developed nations fared better through the pandemic, especially those with favorable conditions for working from home, such as widely available high-quality internet. In contrast, developing countries came in last place in the rankings, due to factors such as families with a high proportion of young children and low internet quality (Bana et al., 2020).

According to (Gottlieb et al., 2021), the low percentage of remote working adoption in developing nations could affect the possibility of their habitants to keep their jobs in case of another global disruption. The vulnerable groups are the less likely to access remote positions, widening the broad economic gap existing in these countries.

2.4 Change management and remote working

Change management is described as “the process of continually renewing an organization’s direction, structure, and capabilities to serve the ever-changing needs of external and internal customers” (Moran & Brightman, 2000). Successful change management requires understanding the situation which is causing the change and the potential impact this could cause. The way a certain group views a particular change situation will depend on the organizational culture, the source of this change, the social, employment and educational background of each individual and how management handle the change (Paton & McCalman, 2008).

Many employees found themselves in a new working environment caused by the pandemic, and they improvised the best they could to adapt to the unknown teleworking conditions. However, the statistics indicated a deterioration of health and working environment due to the accelerated transformation, showing the importance of planning and managing change implementation (Rymaniak et al., 2021).

2.5 Conclusion from literature review

After reviewing several journals and many other sources, some gaps have emerged from the data available regarding remote working in the construction industry:

- Most papers concerning remote collaboration in the construction sector are written by Europe-based scholars, which shows the need for more research from other continents to understand the extent and impact of this topic.
- Since more than half of the examined journals were literature reviews of previous publications, it could be extremely helpful to update academic information regarding remote work in construction with first-hand information from the field.

- It is notable to mention the small amount of information regarding remote collaboration among construction workers in developing countries. The aim of this dissertation is to explore the way remote working has been recently conducted in Latin American construction industry.

Consequently, more research is needed on comparing different remote collaboration approaches, as well as critically reviewing the benefits and detriments of this method of working in order to understand how it could be used in the construction industry more efficiently.

2. Research Methodology

The methodology used in this investigation started off from the chosen methodological framework, which in this case is the Nested Model proposed by (Kagioglou et al., 2000). Since the object of study in this research are the impressions of workers involved in the construction sector, interpretivism is the philosophy selected, as it fits well with the intent of the investigation.

Interpretivism requires the researcher to understand the meaning of certain experiences for the subject, how they are perceived by others and why such perceptions are made (Clark et al., 2021). Here lies the key difference between interpretivism and positivism: the ability of the subject of study to understand and describe their own experiences (Mclaughlin, 2011).

The research has been approached in an inductive manner, working exclusively from the participant experiences, analysing raw data to identify repetitive themes related to the research questions (Azungah, 2018). The conclusions are drawn directly from the examination of the collected data and not from assumptions made beforehand (Thomas, 2006).

Since this research focuses on capturing the opinions and experiences of a group of individuals regarding remote working in the Latin American construction industry (Wisker, 2008), qualitative research methods will be fundamental for exploration of the topic and development of conclusions, as the variables are unknown (Creswell and Creswell, 2018). When dealing with changing work contexts and the complexity of significant organisational transformation, qualitative research offers an effective range of methods to discover and understand the impact behind an issue (Creswell and Creswell, 2018; Wisker, 2008). Subsequently, a qualitative data collection method is used to collect impressions from the participants of this study, sampling 20 professionals from the Latin American construction industry.

The semi-structured interviews were based on 10 questions to understand:

- what has driven the implementation of remote working in the construction industry
- which strategies have been used in the Latin-American construction industry to adapt to remote working
- how are these companies applying these strategies, and
- what are the challenges faced by this new mode of working in the Latin-American construction industry

Interviewees were questioned about their experience through the implementation of remote working in their respective companies in order to gather first-hand accounts on how the Latin American construction companies have managed the change from physically working in an office to allowing their employees to telework from various sites. With the help of Nvivo as the main data analysis software, the data collected from the interviews was categorized by codes, grouping them under common themes related to the research objectives

3. Data analysis method

Data analysis entails the critical examination of the data collected to identify patterns, in order to find satisfactory answers for the research questions (Dudovskiy, 2022). According to (Lacey & Luff, 2009) there are several approaches available to analyse qualitative data, such as grounded theory and framework analysis.

The framework analysis has been selected as the systematic approach for this thematic analysis, as it involves clear linear stages for the thematic analysis of information.

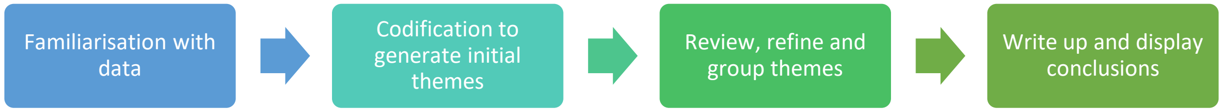

Fig. 1. Framework analysis stages.

With the help of Nvivo as the main data analysis software, the data collected from the interviews was categorized by codes, grouping them under common themes related to the research objectives, as displayed in the figure bellow:

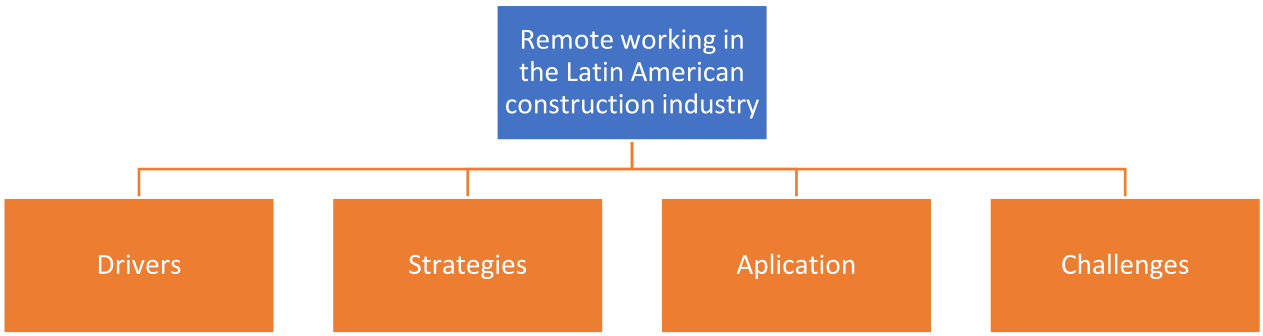

Fig. 2. Themes according to research objectives.

4. Results and discussion

4.1 Drivers behind the implementation of remote working

Question 1: What was the cause behind the implementation of remote working in your company?

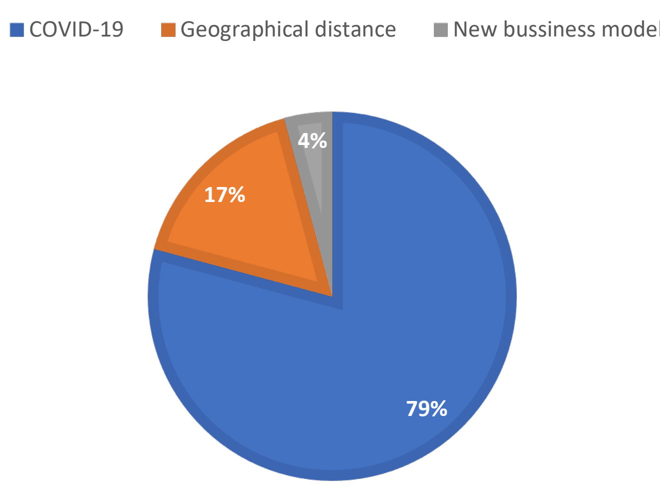

Fig. 3. Drivers behind the implementation of remote working.

As shown in the figure above, an overwhelming majority of the companies analysed started to work remotely because of the COVID-19 pandemic.

Question 2: What advantages can you identify in this mode of working?

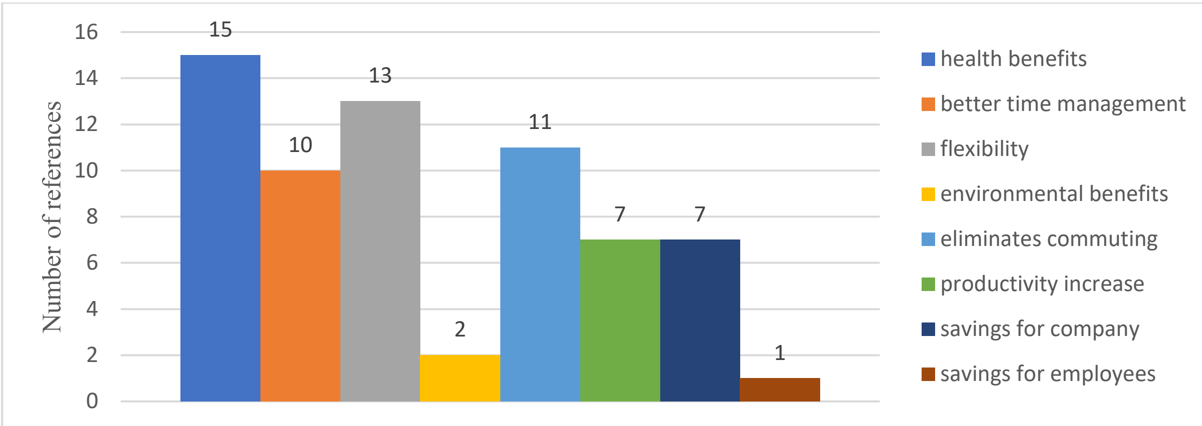

Fig. 4. Advantages of teleworking according to interviewees

By implementing this mode of working, employers can benefit from cost effective personnel, whereas employees get a better life balance (Felstead & Henseke, 2017). This aspect was highly valued by the interviewees, agreeing with employees from many other industries and locations that have been pushing in favour of more flexible work arrangements as a result of their positive experience with remote work during the pandemic.

4.2 Strategies for the implementation of teleworking in the Latin American construction industry

Question 3: What tools, software, etc. have been used in your company to implement remote working?

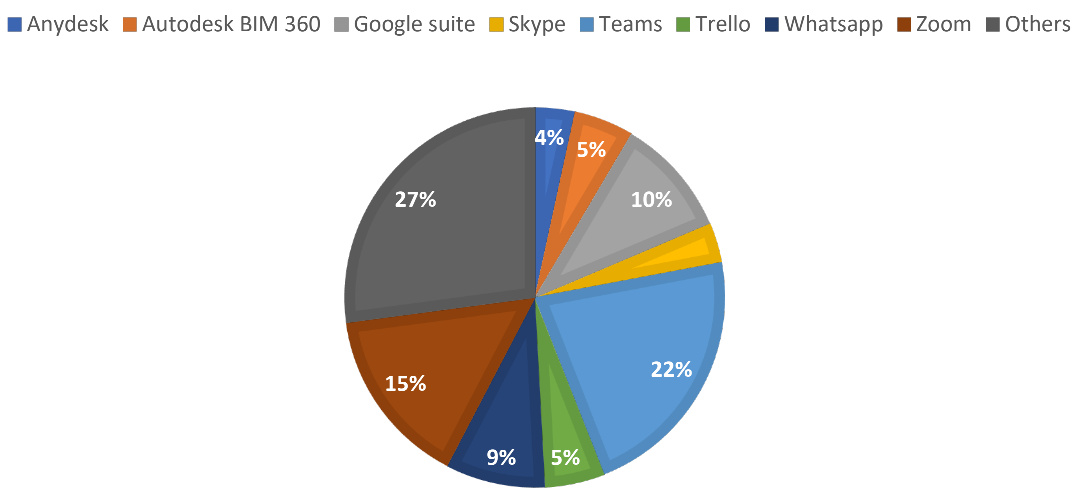

Fig. 5. Software used in the companies examined for the implementation of remote working.

Microsoft Teams was the most popular tool among the investigated firms for communication. The affordability of this software compared to similar options, and its seamless integration with other widely used tools could be some of the reasons why this resource led this area of the investigation. Other software mentioned by the participants, aside from the ones showed in the figure 14 were Plannerly, Bluebeam, Asana and Dropbox.

It is remarkable the minimal implementation of software properly oriented to collaboration in the construction sector, such as the platform of Autodesk BIM 360. This would have been a valuable resource for the implementation of remote work in the aforementioned companies, as BIM can aid in alleviating some of the significant challenges of managing and developing effective stakeholder collaboration during remote construction projects (Arayici et al., 2012).

Question 4: Which techniques have been used in your company to adapt to remote working?

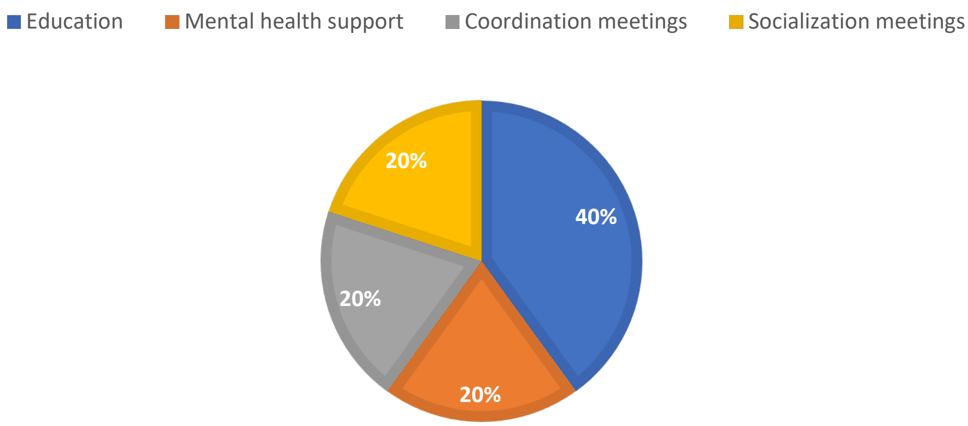

Fig. 6. Techniques used in the companies examined for the implementation of remote working.

The companies examined focused on educating their employees about the implications and best practices of remote working, as well as giving them mental health support to facilitate the adaptation process.

4.3 How are Latin American companies leading the change to remote working?

Question 5: What new rules were applied in your organization for the implementation of remote working?

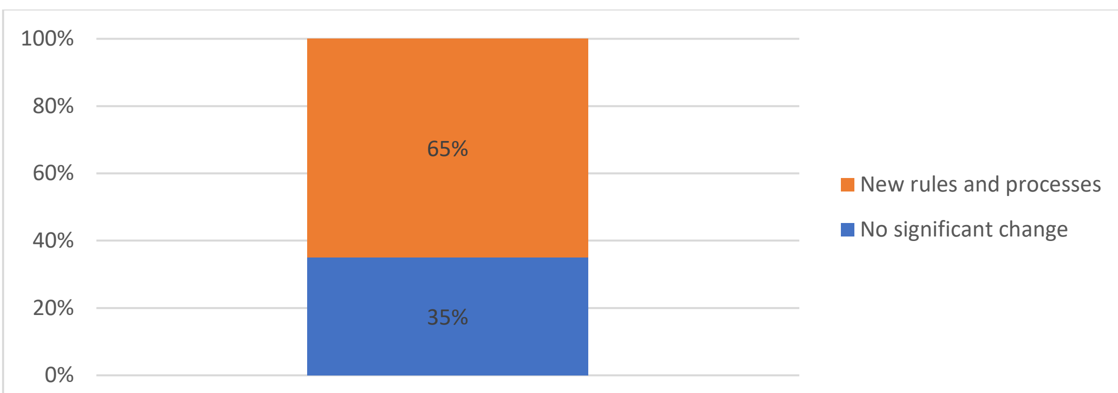

Fig. 7. Change in organization rules or processes.

Even though, 35% of participants commented that the processes in their companies basically remained the same, with the difference that they we were using new communication tools, most of them noted that new rules were implemented, for example, the virtualization of some procedures in the business. An important point touched by several participants was the need for their companies to implement new rules regarding time boundaries, with the purpose of enforcing respect for the non-labouring hours among co-workers as well as between management and subordinates.

Question 6. Did your company follow any change management process to implement remote working? Please elaborate in this process.

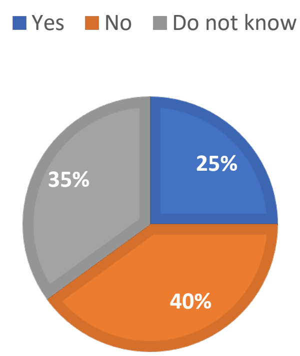

Fig. 8. Use of change management for implementation of remote working.

Regarding the exercise of any change management process to facilitate the shift from traditional work methods to telework, only 25% of participants could identify a structured process applied in their enterprise, while an astounding 35% ignore if there was any individual or department in charge of directing the operation.

The key to effective change management, according to (Paton & McCalman, 2008), is first identifying appropriate problem owners, and then selecting a management methodology to provide a means of transition. Most companies did not assign a responsible to manage the change process, but as pointed out by (I-02) and (I-09): "everything was done on the fly".

The start of remote work in many of these companies coincided with the onset of the COVID-19 pandemic, which affected the way they implemented changes to incorporate the teleworking method. The few successful instances support the claim made by (Stride et al., 2021) that construction organisations could benefits from adopting a systematised approach for the introduction of remote working.

4.4 Challenges of remote working in the Latin American construction industry.

Question 7: What disadvantages can you identify in this mode of working?

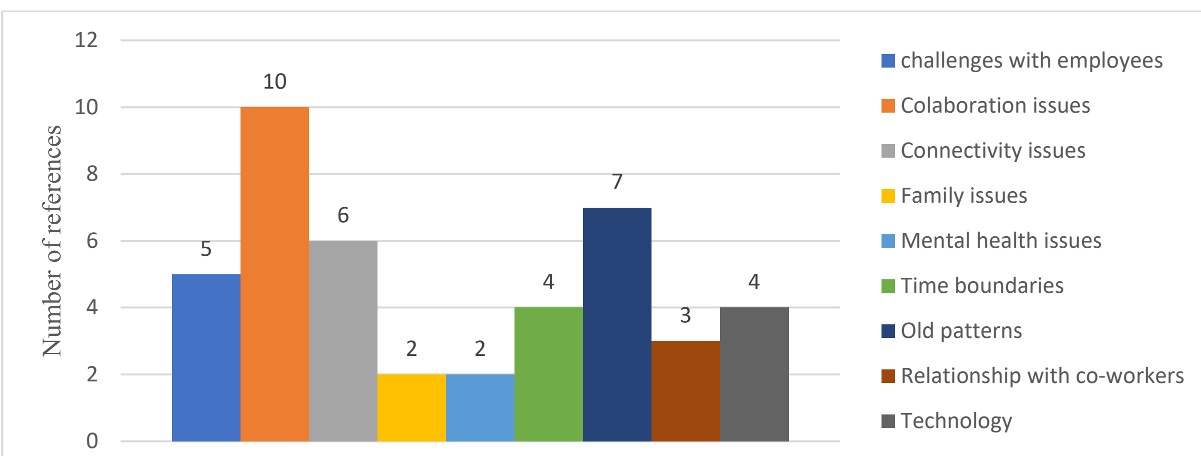

Fig. 9. Disadvantages of teleworking according to interviewees.

Even though most interviewees commented that they had no problems adjusting to remote working, they could still recognize many disadvantages regarding teleworking, ranging from mental and social challenges to technological barriers.

Connectivity issues was among the prevalent challenges cited for the implementation of remote working in the region, confirming the results of (Bana et al., 2020). Almost all participants reported having problems while teleworking due to the poor signal quality in the area or the total loss of the service lines.

Some participants mentioned that the relationship with their co-workers cooled down, which might aggravate the collaboration while working remotely. Other disadvantages mentioned by the participants were the tension that remote work creates when the labour is done in the common family environment, as well as the stress caused by teleworking time when it overlaps with the employee's free time and personal space. These comments were consistent with the literature, as several studies found that telework agreements could affect the work-life balance of an individual, which can impact the performance indicators for the company (Popovici & Lavinia Popovici, 2020). For these reasons, (Wöhrmann & Ebner, 2021) advocated for the implementation of guidelines to regulate remote working in order to protect the mental health of teleworkers.

Question 8: Have you experienced any issues because of switching from working in an office to working remotely?

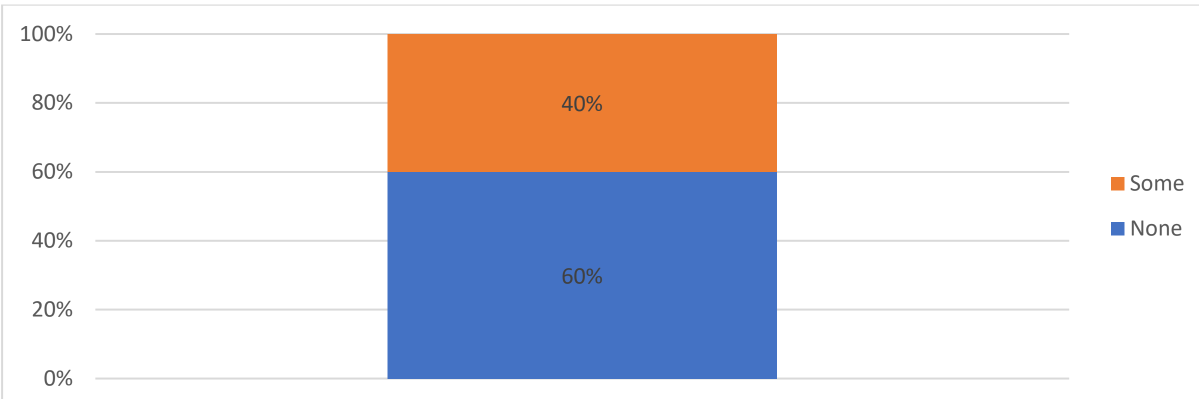

Fig. 10. Personal issues when shifting to teleworking.

The majority of the participants in this study stated that they had no trouble adjusting to teleworking. Managers were more affected than staff in intermediate positions through the implementation of remote working due to the COVID-19 pandemic, as it was more challenging to lead their teams remotely (Jallow et al., 2021); (Park & Cho, 2022), but "some difficulties with management can be improved with practice", as commented by (I-20).

Question 9: Has remote working continued in your enterprise? Please detail why it has/has not continued.

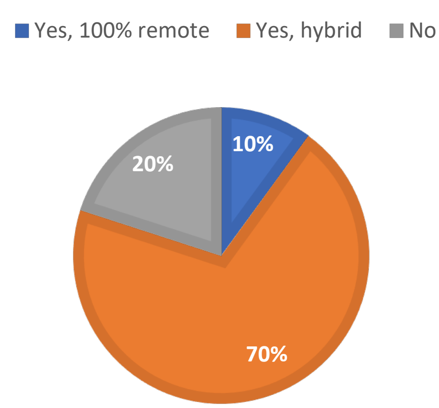

Fig. 11. Continuity of teleworking conditions.

Even though some companies only maintained the teleworking conditions while the authorities demanded it, most of them continued with a hybrid modality that allowed their employees to choose their work environment and schedule, as long as they meet the assigned goals. This has allowed the aforementioned employees to continue with their work in situations of force majeure, as well as giving them the flexibility to attend personal appointments without affecting the development of their work.

In a recently conducted study, 81% of respondents agreed that the hybrid model is the best way to work (WeWork et al., 2022). Nevertheless, the old paradigms of executives and clients in the Latin American construction sector interfere with the implementation of new ideas that can take the construction sector to the level of modernity that other industries hold.

Nevertheless, we still do not have the technology to perform many of the functions in the construction workflow remotely. As remarked by 20% of the participants, the physical presence of the worker is required in many of the processes. This is one of the reasons why telework is more prevalent in 'white collar' occupations (Lyons et al., 2006)

5. Conclusions and recommendations

This investigation has provided a deeper insight into the topic of remote working, focused in the Latin American construction sector. Little research has been conducted in this area, which makes this study extremely valuable for commercial, academic and governmental organisations in order to fully understand this phenomenon. The results of this study are summarized below:

- The principal cause for the implementation of telework in the construction industry has been the COVID-19 pandemic.
- Teleworking has been implemented in the Latin American construction sector mainly by using communication and data transmission tools, as well as training and giving support to employees.
- Latin American construction companies are not fully exploring the equipment and software available to carry out remote work in this industry.
- Very few companies in the Latin American construction industry are applying change management principles to facilitate teleworking conditions in their business.
- Social and mental constraints, as well as technological obstacles are the main challenges for the implementation of remote working in the Latin American construction industry.

It is remarkable that the interviewees did not mention any of the privacy and security concerns associated with remote collaboration found in the literature. Future research could explore this factor, and potential solutions to this issue. Executives from AEC companies should contemplate the adoption of new working practices to protect their business from unexpected threats, and to keep up with developments in this area.

The limitations of this research in regards of sampling could hinder the generalization of the results. Nevertheless, this study is still significant, as it can guide further investigation regarding the implementation of telework in Latin America. Finally, it is recommended to evaluate in future research how to enhance remote cooperation with the help of technology, as well as the implied cost-benefit.

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Understanding Sustainable Delivery Organized by Construction Firms: An Analytical Framework

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Abstract

Pressure is mounting for construction firms to practice sustainable development. However, it is argued that sustainability remains conceptual and unactionable in the empirical context. To address this problem, we use the method of literature review to establish an analytical framework to guide the contextual understanding of how construction firms deliver projects sustainably. First, we situate sustainability within a project context. As a result, activities that might be challenged when considering sustainability in project delivery are identified, including the definition of deliverable criteria, project scheduling, procurement, and risk management. Second, based on institutional logic, we propose an analytical framework of hybrid organizations. Constituent elements of the framework, including incompatibility, centrality, structure, tension, and response, are theoretically interpreted. Next, we investigate the constraints that construction firms may encounter when hybridizing sustainability perceptions in their practice. Particularly, business logic and sustainable logic are carefully analyzed and compared. Finally, we briefly discuss how to contextualize this analytical framework in sustainable project delivery. Overall, this paper contributes to an analytical framework for a contextual understanding of sustainable project delivery in construction firms.

Keywords

Sustainable delivery, hybrid organization, institutional logic, tension management, construction firm.

1. Introduction

Sustainable development is a significant global concern, which presents challenges to various sectors. In the construction sector, project delivery is required to be conducted in a sustainable manner for both the construction and operation phases (Aarseth et al., 2017). Thereby, various principles and prescriptions are introduced. For example, project procurement is required to achieve social justice by preventing bribery and other non-ethical behaviours (Silvius, 2013; Tharp, 2013). Nevertheless, the current practice of sustainable delivery remains inefficient (Armenia et al., 2019; Hueskes et al., 2017). Some studies suggested a feasible direction by detailing these prescriptions (e.g., Stanitsas et al., 2021). However, we argue that such a single direction is problematic since detailed prescriptions might remain conceptual rather than practical. Therefore, we suggest an empirical understanding of how construction firms could conduct sustainable development is also significant. In practice, construction firms are traditionally guided by business orientation to deliver projects within cost, time, and quality constraints. However, introducing sustainability means the business focus is hybridized with a sustainability orientation. These two orientations are interrelated but potentially competing, thus creating tensions in practice (Laasch, 2018). Against this background, we propose an analytical framework to guide empirical investigation to understand how construction firms could deliver projects sustainably.

The remainder of this paper is structured as follows: Section 2 explains how sustainability can be understood in a project context. Moreover, we identify the project activities that are being challenged in sustainable development, which implies the pressures on firms. To navigate the empirical understanding, we establish an analytical framework of hybrid organizations. Section 4 provides a preliminarily contextualized understanding of the framework. Notably, a comparison between business and sustainable perceptions is conducted. Finally, section 5 presents the conclusion and future work suggestions.

2. Understanding sustainability in the project context

2.1 Defining sustainability

The definition of sustainability is encompassing, yet ambiguous (Hopwood et al., 2005; Kiani Mavi et al., 2021). One common meaning aligns with the 1987 World Commission on Environment and Development report:

"development that meets the needs of the present without compromising the ability of future generations to meet their own needs." More theoretically, sustainability is often conceptualized as a three-dimensional term comprising environment, society, and economy (Elkington, 1997). These three dimensions are complementary but potentially contradictory (Kaivo-oja et al., 2014) and must be considered simultaneously (Azapagic & Perdan, 2000). Furthermore, some additional dimensions can be found in the literature, such as technology (Hasna, 2007), temporality (Howe, 1997; Seghezzo, 2009), and psychology (Corral-Verdugo et al., 2010; Seghezzo, 2009). Overall, despite extensive attempts to define sustainability, it remains conceptually ambiguous. Such "constructive ambiguity" (Robinson, 2004) could hinder the implementation of sustainability (Hugé et al., 2013). It is argued that sustainability should be contextualized to produce a concrete and operational definition (Briassoulis, 2001). For example, when discussing corporate sustainability, Van Marrewijk (2003) emphasises that the best definition should match the organization's aims, intensions, and fit with its strategy. Thus, the context-specific understanding of sustainable development is fundamental and significant. In this paper, we will establish an analytical framework to help understand sustainable project delivery through the lens of construction firms.

2.2 Delivering projects for sustainability

Projects as an instrument for change are pivotal to sustainable development (Silvius et al., 2012). As mentioned above, some principles and prescriptions are introduced for construction firms to adhere to, which place new demands on delivery activities. Some detailed considerations for sustainable practice are reviewed below.

Project deliverable criteria. Traditional criteria for project delivery reflect a narrower scope by emphasizing time, cost, and especially quality (e.g., PMBOK Guide). However, by incorporating sustainability, the narrow scope became increasingly inadequate. In this instance, the boundary of deliverable criteria is stretched (Labuschagne et al., 2005; Silvius & Schipper, 2016). On the one hand, more environmental, social, and economic requirements need to be considered in the project's objectives and intended output (e.g., Shen et al., 2010). On the other hand, from the point-of-view of time, projects should not only be constructed in a sustainable manner, but, more importantly, operated as such for a long term (Aarseth et al., 2017). That means the deliverable criteria should be redefined more sustainably from the perspective of the entire life cycle.

Project scheduling. When defining and sequencing the project activities, some specific activities or methods can be considered and introduced (Silvius & Schipper, 2014). Jaillon and Poon (2008), for example, recognized that prefabrication in dense urban environment (like Hong Kong) is sustainable than conventional cast in-situ construction. The study shows the prefabrication can significantly improve the quality control, environmental performance, site safety, and reduce the labour demand. In addition, some advanced methods are proposed to balance the multiple sustainable considerations when scheduling project activities (e.g., Askarifard et al., 2021; Habibi et al., 2019). That also means, these specific sustainability-oriented activities implicitly require that project management profession, especially project managers, updates the scheduling capability.

Project procurement. Both the procedure and the selection criteria of suppliers can impact sustainability in project procurement (Silvius & Schipper, 2014). For the procurement procedure, it is essential to ensure fairness and transparency in the process to achieve social justice (Ogunsanya et al., 2019). For example, Owusu et al. (2019) suggest that "cleaner" procurement actions should be deliberately taken in the contract and the post-contract phase to prevent corruption in the developing countries. For the selection criteria of suppliers, the sustainable performance of potential suppliers should be appraised carefully (Jahangirzade et al., 2021). For example, construction materials used in the project should be environmentally friendly, durable, and recyclable.

Project risk management. A risk is an uncertain event or condition that, if it occurs, can affect a project's objective (PMBOK Guide). Logically, as the project's objectives change to achieve sustainability, the risk will change and need to be re-identified. At the very least, environmental and social risks should be included. Meanwhile, other risk management activities, such as risk assessment and treatment, should also be adjusted (Chawla et al., 2018; Winnall, 2013). Limited work notes how risk treatment can be achieved in an extensive stakeholder landscape in sustainable development.

These demands for delivery activities pose challenges for construction firms to think about how sustainability should be incorporated. Arguably, the detailed prescriptions remain conceptual and without considering the practical limitations. Thereby, we suggest that exploring how sustainability could be incorporated empirically is also necessary. To navigate the contextual understanding, we will establish an analytical framework that investigates how construction firms organize sustainable project delivery.

3. Conceptualizing an analytical framework of hybrid organizations

3.1 Institutional logics

From a neo-institutional perspective, institutional environments provide meaning and constraints to social actors and shape their actions (e.g., Meyer & Rowan, 1977). Such influence can be carried through "institutional logics" (Friedland & Alford, 1991), and exerts on organizations via regulations, normative prescriptions, and cognitive expectations (Scott, 2013). Thornton and Ocasio (1999: 804) defined institutional logics as "the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality." Accordingly, institutional logics can be used to understand the relationships among organizations, actions, and broad institutional environments.

Moreover, the environment at any given time imposes multiple institutional logics on organizations. Sometimes, the influence or demands from different logics might be competing (Pache & Santos, 2010). These competing logics create tensions that can confuse organizations and ultimately impact their behaviours (e.g., Thornton, 2002). Researchers argue that organizations experience these conflicts differently (Fiss & Zajac, 2004; Greenwood & Hinings, 1996). Particularly, when logics influence the organization equally, rather than one logic dominating another, conflicts can be more extensive and severe (Besharov & Smith, 2014). Thus, in some situations, the competing institutional demands may lead to organizational paralysis or breakup (Pache & Santos, 2010).

3.2 Hybrid organizations

Hybrid organizations have long been recognized by scholars. Their existence seems to be counterintuitive, since the combination of opposing institutional logics that conventionally do not go together (Battilana & Dorado, 2010). For example, biotechnology firms are hybridized with competing logics from academic and business sectors (Powell & Sandholtz, 2012). Such heterogeneous characteristic challenges the understanding of organizational behaviour (Greenwood et al., 2010). Accordingly, hybrid organizations can also offer a lens to understand how generative possibilities might be realized. Early studies tended to treat hybrids as binary, characterizing organizations as either hybrid or not (e.g., Albert & Whetten, 1985). Recently, some scholars put forward that the configurations of hybrid organizations can vary along with some variations (Battilana & Lee, 2014; Besharov & Mitzinneck, 2020). Meanwhile, studies also start to explore the consequences of these varied configurations (e.g., Besharov & Smith, 2014). For example, Smith and Besharov (2019) investigate the changed configurations of business and social mission inside a social enterprise, as well as their varied consequences in terms of strategic tension and identity meaning. This section develops a conceptual framework for understanding configurations of hybrid organizations and their consequences. Figure 1 indicates a summary.

3.3 Configurations and consequences of hybrid organizations

For configurations, at least three elements of hybrid organization could be identified in the extant literature. The first one concerns the incompatibility of institutional logics. That is, to what degrees do logics enable contradictory or consistent perceptions and related practices (see Besharov & Smith, 2014; Raynard, 2016). In other words, logic incompatibility is used to describe situations where perceptions of multiple institutional logics are difficult to integrate, and related practices are difficult to adhere to simultaneously. In addition, the centrality can also represent the configurations of logics. It is defined as "the degree to which multiple institutional logics are treated equally valid and relevant to organizational functioning" (Besharov & Smith, 2014, p. 369). Accordingly, centrality is higher when multiple institutional logics are equally instantiated in organizational functioning. By contrast, centrality is lower when only one principal logic guides core organizational practices. A third element is the structure, which involves how related practices governed by institutional logics are structured within organizations. Two distinctive types of structurization - blended and differentiated hybridization, are recognized (Besharov et al., 2019; Greenwood et al., 2011). For the former, practices related to multiple institutional logics are combined and blended. Whereas for the latter, practices are compartmentalized into subgroups influenced by different institutional logics (see Ebrahim et al., 2014). Studies also show that blended and differentiated structurization can be co-exist in hybrids (Besharov & Mitzinneck, 2020).

For consequences, a concerning one for hybrid organizations is the need to manage tensions. The three elements discussed above are not just for describing configurations of hybrids, but also have implications for understanding the consequential tensions. In more detail, incompatibility would directly influence the tensions generated inside hybrids (see Besharov & Smith, 2014). The higher the incompatibility of institutional logics, the more tensions are likely to generate. Similarly, tensions may be extensively magnified in hybrid organizations where the centrality is high. As for the structure, blended organizations might have more conflicts since multiple separated subgroups, guided by different logics, may seek to dominate in integrated activities. There are also some studies exploring responses to tensions. For example, based on Oliver (1991)'s work, Pache and Santos (2010) propose several strategical responses to competing logics, including compromise, avoidance, defiance, and manipulation. More specifically, compromise is an attempt to partially comply with requirements from different institutional logics. Avoidance means hybrids try to ignore such requirements. Defiance indicates explicit rejection of at least one of the demands from institutional logics. Manipulation is an active attempt to alter the demands. After that, the potential results of these strategical responses are further discussed (see Pache & Santos, 2021).

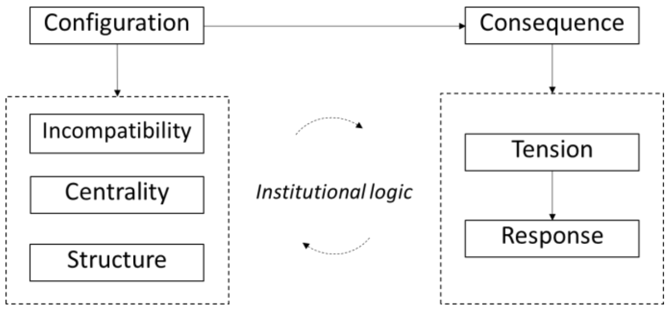

Figure1: Analytical framework of hybrid organizations.

4. Contextualizing the analytical framework in sustainable project delivery

4.1 Competing institutional logics at play

Previously, the construction firm is mainly guided by the business logic, which pays attention to profitability. With the introduction of sustainability, the business logic is hybridized with the sustainability logic. These two logics are interrelated and potentially competing (Montiel & Delgado-Ceballos, 2014), which may generate tensions on the delivery practice, and eventually harm sustainable development. Understanding how these two logics manifest and conflict in practice is the first step to figure out how construction firms could deliver projects sustainably. A detailed contrast between business and sustainable logics is shown in Table 1.

Table 1: The contrast between business and sustainable logics.

Business logic	Sustainable logic
Profit-orientation	Economic orientation Environmental orientation Social orientation
Short-term based on projects Medium-term based on firms	Long-term orientation
Project level Organizational level	System level

Profit-orientation vs. economic, environmental, and social orientations. First, the economic efficiency for project delivery may be the opposite of the profit maximization for construction firms. For example, corporates may overuse the material or workforce to create additional revenue from the project clients, which might not be economically efficient for projects *per se*. Then, for the environmental dimension, it is evident that committing to environmental performance may imply a high cost (Schaltegger & Synnestvedt, 2002), such as the development of new environment-friendly but costly construction techniques or materials. Similarly, some studies highlight the conflicts between economic and social dimensions that exist in many situations (e.g., Boyd et al., 2017; Orlitzky et al., 2003).

Short-term based on projects and medium-term based on firms vs. long-term orientation. The essence of sustainability is intergenerational equity. Hence, long-term consideration in sustainability is a significant feature (Bansal & DesJardine, 2014). This orientation stands in sharp contrast to the temporary nature of project construction. Furthermore, for a construction firm, it usually mobilizes resources and coordinates activities in temporary project-based organizing. For example, firms spend several years to construct a mega-infrastructure, which might have may have a profound impact on generations. It is challenging for the profession to take long-term considerations into account.

Project and organizational level vs. system level. A system perspective means regarding sustainability as a complex interaction of the environment and society (Valente, 2010). Accordingly, the “system level” can be understood in two ways. First, firms are encouraged to stimulate their initiatives to address the sustainability challenges at the system level (Dyllick & Muff, 2016). Second, when pursuing such initiatives, firms should consider the sustainable dimensions in a systemic way. However, traditional construction firms are prone to direct attention to the project level and organizational outcomes. Contributions to the system level are often overlooked. To sum up, when hybridizing the business and sustainable logics, construction firms need to consider multiple, interrelated, but potentially conflicting goals; balance the contrasting short-, medium-, and long-term time orientations; link together project, organizational, and system levels' contributions. Thus, the business and sustainable logics can be regarded as two competing institutional logics. Furthermore, how construction firms sustainably deliver projects in practice and navigate tensions can be empirically contextualized by the above analytical framework.

4.2 Contextual understanding of sustainable project delivery

Incorporating sustainable development into the project delivery can be regarded as a hybridization of business logic and sustainable logic. By virtue of the analytical framework, this section will contextualize a preliminary analysis on sustainable delivery from the perspective of construction firms, including the configurations and consequences of hybrid organizations.

The incompatibility of business logic and sustainable logic enables the contradiction or consistency of related activities conducted by construction firms. As mentioned before, construction firms might need to balance the specific bidding criteria when purchasing materials. The criteria for the lower price may conflict the criteria for environmental friendliness. Notably, the incompatibility of logics is not static, but may vary over time (e.g., Ramus et al., 2017). That means these two orientations in the construction firms may change at different points in time. Centrality stands for whether the business logic and sustainable logic are equally important, or one is dominant, and another plays a peripheral role. Empirically, the integration of sustainable practice into the project delivery could influence how firms organize the identify, mission, strategies, and practices (e.g., Yuan et al., 2011). Moreover, evidence shows that external actors (like government and clients) and internal actors (like leaders in construction firms) could shape the organizing of centrality (Pham & Kim, 2019). As for the structure element, some sustainable practices, such as life cycle cost analysis and material use considerations, can be directly blended into the project practice (Yates, 2014). However, some practices might be separated from traditional practices, such as specialized construction waste reclamation.

Sustainable concerns could give rise to tensions as they go counter business-as-usual practices (Scheyvens et al., 2016). Furthermore, according to the analytical framework, different configurations could theoretically result in different tension manifestations. The degree of incompatibility, for example, could obviously affect conflict generation and its level. Under such circumstances, more empirical studies could be taken to investigate manifestations and mechanisms of tensions in a sustainable project context. As for the response, construction firms are not passive recipients of competing logics, but will active response to pressures caused by competing logics. Among various responses, the strategy of "defiance" has attracted the attention of scholars, since organizations could ceremonially respond to pressures, but would not take real actions. For example, firms may use symbolic strategies to deal with social responsibilities (Marquis & Qian, 2014). Contextually analysing the tensions and responses would sharpen the understanding of sustainable delivery.

5. Conclusions and further research

The ambiguous definition of sustainability makes the concept incomprehensible and unactionable. Against this background, this paper puts sustainability into the project context to understand. Accordingly, some project activities that sustainability might impact are identified, including the deliverable criteria, project scheduling, project procurement, and risk management. Later, we used the method of literature review to propose an analytical framework of the hybrid organization to help understand how construction firms empirically organize sustainable delivery. Finally, the framework is preliminarily contextualized by describing how the business logic and sustainable logic are embedded in practice. Meanwhile, this framework can also help practitioners to check the sustainable activities in use and provide insightful ideas for future firms' development. As a whole, this paper contributes an analytical tool to explore sustainable practice empirically. Such a contextual lens could broaden our understanding of different pathways to sustainable development. We hope to stimulate further work that sheds light on a more nuanced analytical framework, empirical investigations, and a combination of "best practices" to guide the development of sustainability for construction firms.

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ENHANCING WOMEN'S PARTICIPATION IN THE CONSTRUCTION INDUSTRYTHROUGH CONSTRUCTION 4.0 TECHNOLOGY ADOPTION IN NIGERIA

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Abstract

The Construction industry is labour intensive, male-dominated and the nature of work is predominantly manual. The manual jobs carried out in the construction industry are both skilled-based and unskilled-based, which require physical presence most times, the use of strength, and are too tedious for most women to fit in. Hence, the adoption of technologies like those of construction 4.0 can further encourage more women's participation in the construction industry. This study aims at promoting gender equality and encouraging more participation of women in the construction industry through the use of construction 4.0. The methodology includes survey design and purposive sampling techniques. Data were analyzed using mean and rank order. The findings revealed that Construction 4.0 technologies include Building Information Modeling (BIM), drones, etc. Among the Construction 4.0 technologies that can enhance women's participation in the construction industry are; drones/ robots for technical assistance, the Internet ofthings/semantics for interconnection and interoperability, and BIM for decentralized decision, etc.The adoption of these technologies can be encouraged by making them readily available at a subsidized rate, upskilling/ reskilling workers, and continuous sensitization of professionals. The study recommends that Government should provide the enabling environment/policies to encourage investment in these technologies.

Keywords

Male-dominated; Construction 4.0; Technologies; Sustainability; Gender Equality

1. Introduction

The construction industry is complex in nature and consists of complex projects which have a large number of divergent systems and require thorough monitoring/ coordination and control from beginning to end (Wood & Gidado,2008). Furthermore, Wood *et al* (2008) stated that the complexity of construction projects can be in terms of the managerial perspective, operative and technological perspectives. Hence, in order for the complex nature of the construction industryand its project to be effectively managed, the managerial, operative (especially the human resource), and technological aspects must be given the utmost attention. The human resource in the construction industry is mainly male-dominated, the participation of women is globally low but more women participate in developed countries than in developing countries (Jwasshaka & Amin, 2020). The construction industry has the least number of women involvement despite the performance ability of women which is at par with those of their male counterparts (Akinsiku &Ajala,2018). A number of reasons have been given for this such as; the masculine nature of jobs, long working hours, the orientation of women being not as strong as men, and the poor image of the industry (Akinsiku &Ajala,2018). The masculine nature of construction jobs, long working hours, and poor image of the construction industry can be related to the slow adoption of technology in the Nigerian construction industry which is largely characterized by its manual nature of job execution which requires physical strength, low productivity, fragmented, nature, etc.

The adoption of technology like those of construction 4.0 can effectively help in mitigating these challenges. Construction 4.0 technology refers to the technological changes in new work methods as it pertains to processes/materials/markets etc. (Forcael, et al 2020). The technologies which make up construction 4.0 allow for a smart construction site such as the use of sensors, BIM models, drones and robots, etc. Therefore, this study aims at promoting gender equality and encouraging the participation of more women in the construction industry through the use of construction 4.0 by a)identifying the various construction 4.0 technologies in use in Nigeria, b)identifying the Construction 4.0 technologies that can enhance women's participation in the construction industry and c) Assessing the ways to encourage adoption of these technologies in Nigeria so as to enhance women's participation in the industry.

2. THEORETICAL FRAMEWORK

The theoretical framework is based on the two-factor theory (**Herzberg's motivation-hygiene theory) which states** that job satisfaction or dissatisfaction is caused by two sets of separate mutually exclusive factors in the workplace (Nickerson,2021).

He further listed the motivational factors to include; work itself, opportunities for advancement, job status, etc. While, the hygiene factors are; working conditions, policies, rules, relationship with colleagues and superiors, etc.

2.1WOMEN'S PARTICIPATION IN THE CONSTRUCTION INDUSTRY

The Construction industry is male-dominated with only 16.3% representation of women in the industry's workforce (Akinsiku et al,2018). Furthermore, according to Wang, Musi, andSunindijo (2021), women's participation in the industry dropped from 17% in 2006 to 12.9% in 2020. In Nigeria, men make up more than 90% of the Construction workforce (Nigeria Bureau of Statistics,2015), while in the United State of America, women make up only 8.2% and 3.1% of those employed as Construction managers and labourers respectively (Haruna, et al,2016). The participation of women in the Australian Construction Industry is only 11% (Adeniji etal, 2022) and 10% in South Africa (Akinsiku et al,2018).

2.2Barriers to Women's Participation in the Construction Industry

There are numerous challenges that affect women's participation in the Construction Industry and this may vary from country to country, some of these barriers include; Stressful work environment (Lekchiri et al,2020), Sexual discrimination, and Physical incapability (Agapious,2002, Okeke *et al*,2018), masculine nature of jobs, long working hours, the orientation of women not been as strong as men, and poor image of the industry (Akinsiku,2018),

2.3CONSTRUCTION 4.0 AND ITS TECHNOLOGIES

Construction 4.0 is an advanced construction management method that is driven by Industry 4.0 technologies, which allows for the creation of smart construction sites and the optimum performance of the industry (Prieto,2021). It is made up of various technologies such as drones, actuators, Prefabrication, Simulation, Building Information Modeling(BIM), Internet of things, sensor, Cloud Computing Artificial intelligence,3D printing etc.

2.4CONSTRUCTION 4.0 AND WOMEN'S PARTICIPATION IN THE CONSTRUCTION INDUSTRY

The dominance of males in the Construction industry cannot be overemphasized, but the active participation of more women in the industry can be further encouraged throughthe adoption of technology such as those of Construction 4.0. Among some of the barriers which bedevil women's active participation in the industry are; Stressful work environment (Lekchiri etal 2020), Sexual discrimination and Physical incapability (Agapious,2002, Okeke et al,2018), masculine nature of jobs, long working hours, the orientation of women not been as strong as men,and poor image of the industry (Akinsiku,2018), But, these challenges can be surmounted completely or mitigated by Construction 4.0 which embeds the principles of technical assistance through technologies such as drone, robot and 3D printing (Prieto,2021), decentralization of decision through the use of BIM, Cloud computing, interoperability interconnectivity and information transparency through the use of virtual/ Augmented reality(Prieto,2021). Therefore, since the world is going digital and many other sectors are aligning, the Construction industry cannot afford to be left behind. The adoption of these technologies which encourages digitalization, industrialization, and the use of cyber-physical systems can help integrate more women into the industry, bridge the skill gap due to the low participation of women, and thereby increase productivity and efficiency of the industry (Hossain *et al*;2019, Sawhney *et al*; 2020, Forcael *et al*,2020). The adoption of Construction 4.0 technologies helps encourage the recruitment, retention, and job progress of women in the Construction industry.

2.4.1CONSTRUCTION 4.0 AND WOMEN'S RECRUITMENT INTO THE CONSTRUCTION INDUSTRY

A major barrier to the participation of women in the Construction industry is the Poor image of the industry. The adoption of Construction 4.0 can help bring about a change in business and new image fostering by transforming a "dumb" system into a "smart" system, enabling a decentralized system of decision-making through the use of Building information modeling and cloud computing, enabling systems to work together(interoperability) through the use of internet of things, connecting systems together(interconnectivity) through the use of internet of things, providing technical assistance through the use of drones, enhancing safety through the robot use (Prieto, 2021). This can help in recruiting more women into the operational phase of Construction as against the administrative phase in which most women in the Construction industry are concentrated (Haruna *et al*,2016), and more female graduates into the Construction industry (Akinsiku, *et al*,2018).

2.4.2CONSTRUCTION 4.0 AND WOMEN'S RETENTION AND JOB PROGRESS.

Another barrier to women's participation in the Construction industry is the long hours of work, the tediousness of work, and sexual discrimination. The adoption of the fourth industrial revolution in the Construction industry has brought about new competencies such as change and workforce management (Turner, 2021), etc. and a number of Leadership competencies are associated with Construction 4.0 such as Tolerance of failure, Encouragement, Trust-building, Talent management, and Partnership development. These can help motivate, create a better workplace for women, and reduce sexual discrimination. Also, the adoption of technologies such as Drones, the Internet of Things, and Cloud computing can help in reducing long work hours and the tediousness of work as described below;

2.4.2.1DRONE TECHNOLOGY

Drone technology can help encourage more women's participation in the Construction industry. According to Shahmoradi, Talebi, Roghanchi, and Hassanalian, (2020), the monitoring of construction sites and facility management could be enhanced through the use of drones. The adoption of this technology on a Construction site could assist women in site supervision, especially where the site is large involving diverse activities and might involve monitoring high-rise construction activities. It can also help reduce long working hours i.e. save time, improve women's safety (some sites might be potentially dangerous for women, and pose a high risk), and help in assessing high-quality data (Tkáč, & Mésároš, 2019).

2.4.2.2INTERNET OF THINGS

The internet of things(IoT) can help in collecting, and processing large amounts of data, and help improve the quality of life in the Construction industry (Hossein Motlagh, Mohammadrezaei, Hunt, & Zakeri,2020). Data is needed for sustainability and is also very important at every phase of construction. Gathering data, especially at the operational/maintenance may pose a major challenge for women (since it's mainly done manually in Nigeria due to the low adoption of technology), hence the adoption of technologies like the Internet of Things can help reduce sexualdiscrimination.

2.4.2.3 CLOUD COMPUTING

Most construction and Contract documentation are paper-dominated; hence documents are stored in files that might be too many/bulky to access after a long time. The adoption of cloud computing in Construction can help eliminate paper-associated storage challenges and reduce the time spent in searching for files. Furthermore, it could also help reduce cost savings, and enhance flexibility, and security (Srivastava, & Khan,2018).

3.0 METHODOLOGY

The study was carried out among construction companies in Lagos state (Lagos was chosen because it's the commercial centre of Nigeria and a lot of construction work goes on there) with a population of 70 respondents which comprised of both male and female professionals such as Architects, Builders, Quantity surveyors, Civil Engineers, Mechanical and Electrical Engineers, etc. Both Primary and Secondary methods of data collection were used for this study. A quantitative approach was adopted using structured questionnaires (which were the primary data source), Published articles, Journals, textbooks, etc. made up the secondary sources of data collection instruments. The sampling techniques used were purposive sampling techniques because respondents had the requisite experience and were also the primary actors/recipients. Thesample size was determined through the use of the taro Yamane formula ($n = N/ 1+ N(e)^2$), WhereN is the population of the study is the sampling error, where the sample size was 60 respondents. The data were analyzed by mean score, rank order, frequency, tabulation, and percentages.

4. Results

4.1 Profession of Respondent

Table 1 **Table 1 Profession of Respondent**

S/N	PROFESSION	NUMBER OF RESPONDENTS	PERCENTAGE
1	Architect	20	33.33%
2	Builder	10	16.67%
3	Structural Engineer	3	5%
4	Quantity Surveyor	15	25%
5	Mechanical Engineer	5	8.33%
6	Electrical Engineer	7	11.67%
	TOTAL	**60**	**100**

Source: Research Survey (2023)

From table 1, it can be seen that the profession of the respondents are; Architects with a percentageof 33.33%, Quantity surveyors with a percentage of 25%, Builders with a percentage of 16.67%, Electrical engineers with a percentage of 11.6%, 5 Mechanical engineers with a percentage of 8.33% and Structural engineers with a percentage of 5%

4.2 Proportion of Male Respondents to Female Respondents

Table 2 Proportion of Male Respondents to Female Respondents

S/N	PROPORTION OF MALE TO FEMALE	NUMBER OF RESPONDENTS	PERCENTAGE
1	Male	15	25%
2	Female	45	75%
	TOTAL	60	100%

Source: Research Survey (2023)

From table 2, it can be observed that women make up 75% of the total respondents, while menmake up 25% of the total respondents

4.3 Years of Experience of Respondents.

Table 3 Years of Experience of Respondents.

S/N	YEARS OF EXPERIENCE	NUMBER OF RESPONDENTS	PERCENTAGE
1	2-10 YEARS	20	33.33%
2	10-20 Years	35	58.33%
3	20-35 Years	5	8.33%
		60	100%

Source: Research Survey (2023)

From table 3, it can be observed that respondents are mainly between 10-20 years with a percentage of 58.33%, those between 2-10 years with a percentage of 33.33%, and those between 20-35 years with a percentage of 8.33%.

4.4 Construction 4.0 technologies in use in Nigeria.

Table 4 Construction 4.0 technologies in use in Nigeria,

Construction4.0 technologies	**MEAN SCORE**	**RANK**
BIM	5.0	1
IOT	4.98	2
Drone	4.96	3
Robots	4.96	3
Augmented Reality	4.91	4
Virtual Reality	4.91	4
Mixed Reality	4.75	6
Cloud Computing	4.91	4
Big Data Analytics	4.83	5
Semantic Technology	4.83	5

Source: Research Survey (2023)

From table 4, it can be observed that respondents agree that BIM, IoT Drone, Robot, and Augmented reality with mean scores of 5.0,4.98,4.96,4.96,4.91 respectively are Construction 4.0 technologies

4.5

Table 5 Construction 4.0 technologies which can enhance women's participation in theconstruction industry.

Construction 4.0 Technologies that can enhance women's participation in the Industry	MEAN SCORE	RANK
Technical Assistance Drones/Robots	4.83	1
Interconnection/Interoperability IOT/ Semantics	4.65	2
Decentralized Decision BIM/Cloud computing	4.58	3
Information Transparency Virtual, Augmented/MixedReality	4.57	4

Source: Research Survey (2023)

From table 5, it can be observed that respondents agree that the Construction 4.0 technologies that can enhance women's participation in the construction industry are; Drones/Robots (which aids technical assistance) and with a mean score of 4.83, IOT/Semantics (which aids interconnectivity and interoperability) with a mean score of 4.65, BIM/Cloud Computing (which aids decentralized decisions)with a mean score of 4.58, Virtual/Augmented and Mixed Reality(which aids information transparency) with a mean score of 4.57.

4.6

Table 6 Ways to encourage the adoption of Construction 4.0 technologies in Nigeria so as to enhance women's participation in the industry.

Ways in which Construction 4.0 can be encouraged	MeanScore	Rank
Availability of the technologies at subsidized rate	4.3	1
Upskilling/Reskilling of workers	4.1	2
Continuous sensitization of professionals and the Populace	3.87	3
Providing enabling Policies	3.38	5
Providing the necessary political Will	3.57	4

Source: Research Survey (2023)

From table 6, it can be observed that respondents agree that among the ways in which the adoption of Construction 4.0 technologies can be encouraged so as to enhance the participation of women in the Construction industry are; Availability of the technologies at a subsidized rate with a mean score of 4.3, Upskilling/ reskilling of workers with a mean score of 4.1 Continuous sensitization of professionals and the populace with a mean score of 3.87, Providing the necessary political will with a mean score of 3.57 and Providing enabling policies with a mean score of 3.38.

5. Discussion

From the findings above, the various construction 4.0 technologies are; BIM, IoT, Drones,and Robots. This agrees with Krupik, (2022) which identified the Construction 4.0technologies to include BIM, virtual and augmented reality, drones, cloud collaboration (real-time collaboration), the Internet of Things, or wireless monitoring and device connectivity.
The Construction 4.0 technologies which can enhance women's participation in theconstruction industry are; Drones/Robots for technical assistance which agrees with Sotnikand Lyashenko, (2022) which state that robots are solving lots of problems such as low productivity, labour shortage, and

supporting people both at work/ personal lives., IoT for Interconnection/Interoperability agrees with Ibrahim, Esa, and Rahman, (2021) which statethat the interconnectivity of IoT directly/ indirectly acts as a primary medium of communication between humans and construction technology. BIM/Cloud computing fordecentralized decision agrees with Agyekum-Kwatiah, (2018) which states that BIM allows for clash detection through its information sharing capabilities between various departments, Virtual, Augmented/Mixed Reality for information transparency which agrees with Mathivanan, (2017) which states that Virtual reality is very interactive.

Ways to encourage the adoption of Construction 4.0 technologies in Nigeria so as to enhance women's participation in the industry are; Making available these technologies at a subsidized rate, Upskilling/Reskilling workers, Continuous sensitization of professionals and the populace, and providing enabling policies and Providing the necessary political will. This agrees with Nnameti and Eze, (2022) which encouraged the involvement of government and private investors in promoting smart cities through the use of smart technologies. While, Adepoju, (2021) emphasized the need for re-skilling human resources as an integral way of encouraging the adoption of these technologies.

5. Conclusions

The Construction industry is complex in nature and this complexity is both in terms of its technology and operatives. The slow adoption of technology and prevalent male dominance of the sector in Nigeria has further posed a threat to the participation of women in the industry. Therefore, the study identified Construction 4.0 technologies to include; Building Information Modeling(BIM), Internet of Things(IoT), and Drones. The study also identified the various Construction 4.0 technologies that can enhance women's participation in the Construction industry to include; Drones/Robots for technical assistance, the Internet of things(IoT)/ Semantics for interconnectivity. Furthermore, the study enumerated the ways Construction 4.0 adoption can be encouraged to include; making available these technologies at a subsidized rate, and Upskilling/Reskilling workers. Hence, the adoption of Construction 4.0 technologies such as Building Information Modeling(BIM), Internet of Things(IoT), Drones, etc., and encouraging their adoption through their subsidization, upskilling/reskilling of workers, sensitization of professionals/populace can help promote gender equality and encourage the participation of more women in the Nigerian Construction industry. This study is limited to the Construction industry (especially in Nigeria) which is male-dominated and slow in technology adoption. To this end, the study recommends that the concept of outsourcing and insourcing be encouraged within the Construction industry, which will see women knowledgeable in some of these non-construction specific technologies such as the Internet of things, and Cloud computing in other sectors like Information and Communication technology work and provide mentorship for women within the industry. While, the women with knowledge of Construction specific technology such as Building information modeling, and Prefabrication within the industry provide mentorship for those early career women and others. Professionals as well as Construction companies should be adequately sensitized on the role Construction 4.0 technology can play in eliminating these barriers militating againstthe active participation of women in the Construction industry. Also, in other to reduce the cost ofacceptance of these technologies, Construction companies should encourage collaboration withinthemselves and partnership between them and other sectors (that possess relevant skills and technologies), and the Government should provide the enabling environment/policies to encourage investment in these technologies. Further studies should be carried out on how Construction 4.0 technologies can encourage women's participation in the Industry in other climes. This study contributes to knowledge in that previous studies have emphasized the use of these technologies to encourage improved work, productivity, and efficiency in the already male-dominated industry without consideration for bridging the gap on the less involvement of women in the industry. Therefore, this study will help promote gender equality and encourage the participation of more women in the Nigerian Construction industry thereby reducing male dominance. Also, this study will help transition women from non-professional roles in the Construction industry to core professional roles.

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Perquisites of Social Media Applications in the South African Construction Industry

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Abstract

Different sectors of the economy have utilized the social media space and have benefited from its adoption and implementation. The recent COVID-19 pandemic that crippled the global economy also propelled the massive use of social media applications (SMAs) beyond its usual limit while forcing the birth of novel innovations in this regard. However, the construction industry (CI) still lags and continually grapples with the wave of adopting SMAs. This is largely due to the generally known nature of construction stakeholders' and professionals' resistance to change. Hence, this paper assesses the benefits of adopting and utilizing SMAs in the South African construction industry (SACI). The study employed the quantitative research approach using a structured questionnaire survey. The questionnaire survey was administered to registered construction professionals in the South African construction industry. Descriptive statistics and exploratory factor analysis were used to analyze the collected data. The findings from the study revealed 23 beneficial impacts of SMAs in the construction sector. Enhanced company marketing reach, brand awareness creation, prompt access to information, increased company visibility, and cost-effective means of advertisement as the top benefits. The study concluded that the opportunities for marketing, timely communication, awareness, information sharing, networking, and collaboration that social media applications offer have the potential to drastically reinvent the construction space. Governmental and non-governmental multi-stakeholder support and intervention are therefore recommended to ensure the numerous benefits accruable to the use of SMAs are fully maximized in the CI.

Keywords

Construction Industry, Digitalization, Fourth Industrial Revolution, Information, Social Media Applications, South Africa.

1. Introduction

The construction industry (CI) globally is known to be the main driver of the economy. The sector is characteristically complex and unique owing to the multiplicity of stakeholders and activities involved (Fernández-Solís, 2008). However, the CI may not be regarded as one of the tech-savvy sectors due to its signature traditional approach (Ndlovu & Simbanegavi, 2021). The CI has traditionally been known for its slow adoption of technology, but this is changing rapidly with the present fourth industrial revolution (4IR) era. With the advent of new technologies such as Building Information Modeling (BIM), Augmented Reality (AR), and Virtual Reality (VR) among numerous others, the industry is now moving towards a more digitized and interconnected future. This shift is being driven by the need for resilience, greater efficiency, cost savings, and sustainability in the CI.

One of the most significant changes that technology is bringing to the CI is the move towards BIM and other innovative technologies that have characterized the 4IR era. These technologies, especially BIM allow architects and other project stakeholders to collaborate in real time, ensuring that all stakeholders are working from the same set of plans and reducing the likelihood of errors and delays (Diaz, 2016). BIM can also be used to digitally simulate construction processes and projects in geometric mode, allowing stakeholders to identify potential issues ahead of time (Zima et al., 2020). This can result in significant cost savings, rework mitigation, efficiency, client satisfaction, waste reduction, enhanced communication among project stakeholders, and improved safety on construction sites among others (Farnsworth et al., 2015). Another technology that is rapidly changing the face of the CI is VR. By creating virtual models of construction projects, the project team and other stakeholders can virtually compare the as-planned and as-built statuses of projects thereby enhancing collaboration and efficiency (Rankohi & Waugh, 2013). This can help to reduce costly mistakes and improve client satisfaction. To aid an effective management strategy to control hazards, VR can also be used to simulate construction safety programs, allowing workers to train in a safe and controlled environment before entering the actual construction site (Noghabaei et al., 2020). To ensure an amazing user experience, social media applications (SMAs) have been able to effectively and efficiently ensure the interoperability of these technologies. This has resulted in the proliferation and multifaceted functionalities of SMAs within the various sectors of the economy. Likewise, the recent experience of the covid19 necessitated and ensured the widespread adoption and utilization of these innovative applications.

Social media is also now playing a significant role in the CI, allowing clients, construction professionals, contractors, and suppliers to connect in new and innovative ways. Platforms and applications such as Facebook, LinkedIn, Twitter, and Instagram are being used to share information about projects, advertise services, and connect with potential clients. Social media are also being used to interact and build relationships with existing and new clients, improve client satisfaction, and gather feedback in form of reviews. With the significant technological transformation happening in the CI, social media apps are increasingly being used to improve efficiency, reduce costs, and enhance client satisfaction. As the CI continues to evolve, it is important to note that technology and social media will play an increasingly important role in shaping the future of the industry. Hence, this study seeks to assess the perquisites of adopting and utilizing SMAs in the South African Construction Industry (SACI).

2. Social Media Sphere in the Construction Industry

The exponential effect and prominence of social media applications (SMAs) are visible and felt in sectors such as marketing, fashion, entertainment, and hospitality among others(Ndlovu & Simbanegavi, 2021). The CI on the other hand is left behind and not riding on the social media wave. Among other reasons, this is largely traceable to the fact that the CI is technology disinclined and globally known as an industry that relies on manual labour and traditional construction methods, especially in developing countries. Compared to other media sources, SMAs allow users to communicate, share or exchange information more rapidly and in real time. Social media have been able to create a platform for idea sharing, relationships, mobilization, and many more. According to Ngai et al. (2015), the social component of SMAs pertains to interpersonal activities while the media aspect pertains to the internet-enabled technologies and tools that are used to conduct such activities. As defined by Kaplan and Haenlein (2010), social media is a collection of web-based applications that aid the production and dispensation of user-generated content (UGC).

It is noteworthy that SMAs can be utilized for multiple or single purposes in a variety of sectors and disciplines. The multifaced functionalities and usability of SMAs became advanced with the 4IR era and the recently experienced covid19 pandemic. This has seen the interoperability of various innovative technologies in SMAs to enhance functions and maximize user experience. SMAs are categorized into the following namely social networks, messaging applications, picture and video sharing applications, interactive and video sharing applications, discussion forums, publishing and blogging networks, bookmarking and content creation, shopping networks and applications, review networks, audio applications, and video conferencing applications (Kaplan & Haenlein 2010; Liu, 2010; Korda & Itani, 2013; Tuten & Solomon, 2017; Diaz & Mellon, 2021; Shayne, 2021; Chan & Allman-Farinelli, 2022; Minaev, 2022). Notable examples of the SMAs in these classifications are Facebook, WhatsApp, Twitter, LinkedIn, Telegram, Gmail, Instagram, YouTube, TikTok, Snapchat, Quora, Reddit, Pinterest, Amazon, Takealot, Zoom, UberEATS, Spotify, Skype, Google Meets, Microsoft Teams and a host of others.

There are several potential benefits of adopting and utilizing SMAs in the construction sphere. These SMAs can be used to further and maximize academic and educational, income generation, marketing, communications, procurement, and tendering purposes across various fields within and outside the architecture, engineering, and construction (AEC) sector. SMAs are beneficial to the CI as they increase brand awareness and recognition, improve teamwork and collaboration, enhance management and tracking of project schedules, improve communication between project stakeholders, increase project transparency, improve oversight and quality control, increase safety training and awareness, improve customer support and service, enhance customer/client feedback and engagement, increase networking opportunities for construction professionals, increase participation and engagement in industry events, enhance accountability in project execution, enhance community outreach and engagement, improve promotion and marketing of construction projects and brands, and improve project sustainability and corporate social responsibility (CSR) practices (Leader-Chivee & Hamilton, 2008; Meske & Stieglitz, 2013; Ristova, 2014; Çalli & Clark, 2015; Cesaroni & Consoli, 2015; Singla & Gurga, 2015; Mohd Noor et al., 2021).

3. Research Methodology

This study employed the quantitative method of research to assess the perquisites of social media applications (SMAs) in the South African construction industry (SACI). A well-structured questionnaire survey was developed and administered to the respondents to achieve the objective of this study. The respondents sampled are registered construction professionals in the SACI such as architects, civil engineers, construction managers, electrical engineers, health and safety officers, mechanical/services engineers, project managers, and quantity surveyors. A total of twenty-three (23) benefits of SMAs identified through the review of literature were contained in the questionnaire survey. The questionnaire utilized a five-point Likert agreement scale to ascertain the agreement level of the respondents with the identified benefits. The completed and returned questionnaires were collated, reviewed, and cleaned to ensure their completeness and usefulness for the research study. The duo of descriptive and exploratory factor analysis was employed to analyze the retrieved data. A Cronbach alpha value of 0.908 was achieved thereby authenticating the reliability of the data collection instrument and the correctness of the collated results.

4. Results and Discussions

The analysis of the demographics of the respondents showed that 55% of the respondents are males while 45% are females. Quantity surveyors account for 45% of the population sample, construction managers and project managers account for 11.3% respectively, civil engineers account for 10%, mechanical/services engineers account for 8.8%, architects and electrical engineers account for 6.3%, and health and safety officers account for 1.3%. Most of the respondents (51.2%) possess a bachelor's degree followed by those with an advanced diploma or honours degree accounting for 26.3%. A total of 63.7% of the respondents work for private entities, 27.5% work for public/government entities, and 8.8% work for both private and public/government entities.

4.1 Descriptive Analysis: Perquisites of Social Media Applications in the Construction Industry

A total of twenty-three (23) benefits of SMAs were identified and extracted for this study after a review of relevant scholarly works. A mean item score (MIS) analysis was performed on the extracted variables based on the retrieved and collated data. Table 1 below presents the results of the analysis of the perquisites of SMAs in the South African construction industry (SACI). The table presents the results of the study on the perceived benefits of social media applications in the construction industry. The identified benefits are ranked based on their mean scores, which reflect the participants' perceived importance of each variable. The identified benefit with the highest mean score is “Enhance company marketing reach” with a score of 4.56, followed by “Brand awareness creation” with a score of 4.45, and “Access to information promptly” with a score of 4.43. This suggests that participants see social media applications as valuable tools for improving their companies' marketing efforts, increasing brand awareness, and accessing information promptly. The identified perquisites with the lowest mean scores are “Improved organisational performance” and “Aids performance evaluation” with scores of 3.96, followed by “Reduced business operating cost” with a score of 3.93, and “Improved employee performance” with a score of 3.86. Even though they are ranked lower than the top variables, the mean scores are above the average of 3.00 on a 5-point Likert scale. Hence, they are considered significant benefits of social media applications. The standard deviation score measures the amount of variation or dispersion in the data. In this case, the standard deviation represents the degree to which the mean score of each identified benefit varies across the responses from the participants in the study. Looking at the table, the standard deviation values range from 0.644 to 0.978. Perquisites with smaller standard deviation values indicate that the participants had a relatively consistent opinion on their importance, while larger standard deviation values suggest that the opinions were more diverse. For example, “Enhance company marketing reach” has a small standard deviation of 0.653, which suggests that the majority of participants agreed that it was a highly important benefit. On the other hand, “Improved employee performance” has a larger standard deviation of 0.951, indicating that participants had more diverse opinions on its importance. In general, the study suggests that social media applications have the potential to provide significant benefits to the construction industry, particularly in the areas of marketing, brand awareness, and communication. such as improving employee performance and reducing costs.

Table 1. Descriptive analysis of perquisites of social media applications in the construction industry.

Identified Perquisites	Mean Score	Standard Deviation	Ranks
Enhance company marketing reach	4.56	0.653	1
Brand awareness creation	4.45	0.654	2
Access to information promptly	4.43	0.652	3
Increased company visibility	4.41	0.669	4
Cost-effective means of advertising	4.40	0.704	5
Broaden networking connections	4.38	0.644	6
Aids effective communication	4.33	0.792	7
Job creation	4.31	0.908	8
Increased customer base	4.29	0.750	9
Aids active brand building	4.29	0.783	9
Improved customer-company engagement	4.28	0.811	11
Enable effective collaborations	4.25	0.720	12
Aids direct connection to customers	4.21	0.822	13
Increased Website Traffic	4.19	0.813	14
Free social networking avenue	4.15	0.813	15
Improved client experience	4.10	0.773	16
Aids healthy competition among service providers	4.08	0.911	17
Builds customer confidence	4.08	0.854	17
Boost sales and patronage	4.05	0.840	19
Improved organisational performance	3.96	0.920	20
Aids performance evaluation	3.96	0.947	20
Reduced business operating cost	3.93	0.978	22
Improved employee performance	3.86	0.951	23

4.2 Exploratory Factor Analysis: Perquisites of Social Media Applications in the Construction Industry

Further to the descriptive analysis carried out on the retrieved data, exploratory factor analysis was done. Table 2 shows the results of the KMO and Bartlett's Test for the data used in the study. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is used to assess the suitability of the data for factor analysis. The KMO value ranges from 0 to 1, where values closer to 1 indicate that the data is suitable for factor analysis. In this case, the KMO value is 0.745, which is considered to be moderately adequate. The Bartlett's Test of Sphericity is used to test the null hypothesis that the correlation matrix is an identity matrix, which would indicate that the variables are uncorrelated and therefore unsuitable for factor analysis. The test statistic is an approximation of chi-square, and the significance value indicates whether the null hypothesis can be rejected or not. In this case, the test statistic is approximately 1089.576, with 253 degrees of freedom, and the significance value is 0.000, which is less than the significance level of 0.05. This indicates that the variables are sufficiently correlated for factor analysis.

Table 2. KMO and Bartlett's Test for perquisites of social media applications in the construction industry.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.745
Bartlett's Test of Sphericity	Approx. Chi-Square	1089.576
	df	253
	Sig.	0.000

The variance of the components was extracted, and it was discovered that the first component explains the most variance (34.286%) followed by the second component (11.724%), the third component (9.445%), the fourth component (6.101%), the fifth component (5.226%), and the sixth component (4.585%). Together, these six components explain 71.366% of the variance. The remaining components each explain a smaller percentage of the variance. Hence, the six components were extracted as evident from the Scree plot shown in Figure 1.

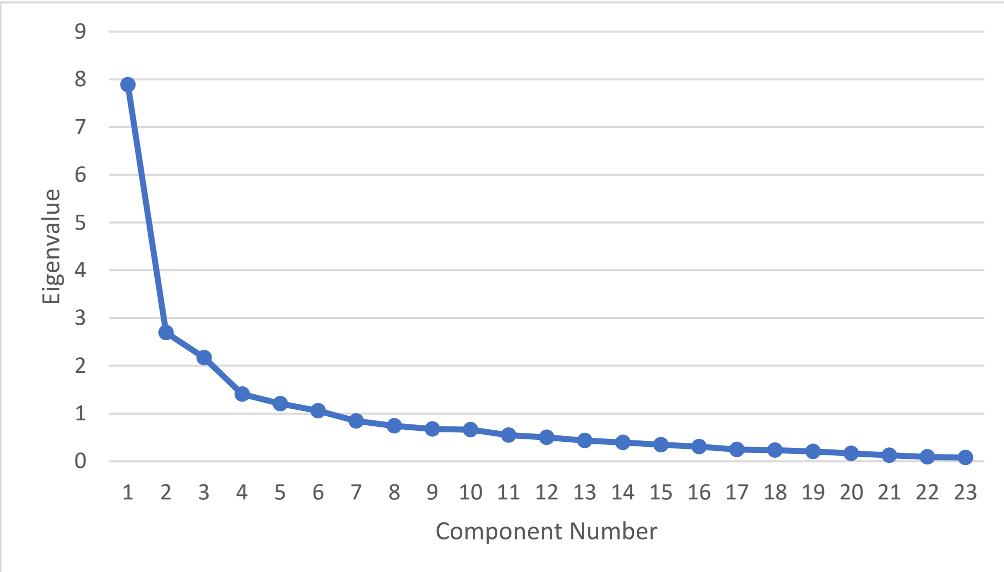

Fig. 1. Scree plot for perquisites of social media applications in the construction industry.

The pattern matrix in Table 3 shows the relationship between the 23 perquisites of social media applications in the construction industry and the six identified components through the principal component analysis. The values in the matrix represent the loadings or correlations between each benefit and the components. The higher the loading value, the stronger the relationship between the benefit and the component. The component clusters are explained as follows. *Marketing and customer engagement*: This component includes perquisites such as an increased customer base, aids direct connection to customers, improved client experience, builds customer confidence, aids active brand building, free social networking avenue, and aids healthy competition among service providers. This component is related to the use of social media applications as a tool for marketing, promoting the brand, and engaging with customers to build trust and loyalty. *Cost-effectiveness*: This component comprises perquisites such as brand awareness creation, enhance company marketing reach, cost-effective means of advertising, and increased website traffic. This component relates to the use of social media applications as a cost-effective alternative to traditional advertising and marketing channels. *Collaboration and access to information*: This component includes perquisites such as enabling effective collaborations and access to information promptly. This component relates to the use of social media applications as a tool to enhance communication and collaboration among stakeholders in the construction industry. *Effective communication*: This component includes only one benefit; aids effective communication. This component relates to the use of social media applications as a tool to enhance communication among stakeholders in the construction industry. *Organisational performance*: This component includes perquisites such as improved employee performance, improved organisational performance, and job creation. This component relates to the use of social media applications as a tool to enhance the performance of employees and the organization as a whole. *Business growth*: This component comprises perquisites such as increased website traffic, boost sales and patronage, and reduced business operating costs. This component relates to the use of social media applications as a tool to increase business growth and reduce operational costs.

In summary, the use of social media applications in the CI has several perquisites, and these perquisites can be clustered into six components, namely marketing and customer engagement, cost-effectiveness, collaboration and access to information, effective communication, organisational performance, and business growth. These components can guide the construction industry in leveraging social media applications to achieve their organisational objectives.

Table 3. Pattern Matrix for perquisites of social media applications in the construction industry.

	Component					
	1	2	3	4	5	6
Increased customer base	0.810					
Aids direct connection to customers	0.735					
Improved client experience	0.702					
Builds customer confidence	0.661					
Aids active brand building	0.605					
Free social networking avenue	0.521					
Aids healthy competition among service providers	0.451					
Aids performance evaluation	0.403					
Brand awareness creation		0.818				
Enhance company marketing reach		0.718				
Cost-effective means of advertising		0.694				
Enable effective collaborations			0.902			
Access to information promptly			0.744			
Broaden networking connections			0.581			
Improved customer-company engagement			0.453			
Increased company visibility			0.414			
Aids effective communication				0.869		
Improved employee performance					-0.858	
Improved organisational performance					-0.808	
Job creation					-0.643	
Increased Website Traffic						0.873
Boost sales and patronage						0.655
Reduced business operating cost						0.358

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.
a. Rotation converged in 17 iterations.

The first component cluster, marketing, and customer engagement highlight the importance of social media applications in marketing, promoting the brand, and engaging with customers to build trust and loyalty in the construction industry. According to Johansson and Hiltula (2021), companies that utilize social media platforms effectively can gain a competitive advantage by improving their marketing efforts, building their brand image, and providing a better customer experience. The cost-effectiveness component of the pattern matrix highlights the benefits of using social media applications for marketing and advertising purposes. According to Appel et al. (2020), the use of social media applications for advertising and marketing purposes can help companies to reach a wider audience, target potential customers more effectively, and track the effectiveness of their marketing efforts more accurately. The collaboration and access to the information component cluster underscore the importance of social media applications as a tool to enhance communication and collaboration among stakeholders in the construction industry. According to Khan et al. (2022), by enabling effective collaboration and providing access to relevant information, social media applications can help stakeholders make informed decisions, improve project outcomes, and drive industry innovation. The component of effective communication highlights the importance of communication in the CI and the potential benefits of social media applications in enhancing communication among stakeholders. According to Argyris and Monu (2015), social media applications can provide a platform for real-time communication, allowing stakeholders to exchange information promptly. The Organisational Performance component cluster emphasizes the importance of using social media applications to improve employee performance, organizational performance, and job creation in the construction industry. According to Marolt et al., (2022), by leveraging the benefits of social media applications, construction companies can improve their competitive position and achieve long-term growth and success. The sixth component cluster highlights the potential benefits of using social media applications for business growth and cost savings. According to Okanga and Groenewald (2017), by leveraging these social media tools effectively, businesses in the CI can increase their online presence, attract more customers, and improve their bottom line.

5. Conclusions and Recommendations

Technology and social media are rapidly transforming the construction industry (CI), with Building Information Modeling (BIM), Augmented Reality (AR), Virtual Reality (VR), and social media applications being at the forefront of these changes. With social media, clients, construction professionals, contractors, and suppliers can connect in new and innovative ways, enhancing communication, and feedback, and building relationships. In line with these perceived benefits, this study provides valuable insights into the benefits of SMAs in the South African construction industry (SACI). The research employed a well-structured questionnaire survey to collect data from registered construction professionals in the study area. From the analysis, the benefits of SMAs were ranked based on their mean scores, with the highest mean score being “Enhance company marketing reach,” followed by “Brand awareness creation” and “Access to information promptly.” However, even the perquisites ranked lowest by participants, such as “Improved organisational performance” and “Aids performance evaluation,” still had mean scores above the average 3.00 on a 5-point Likert scale, indicating their importance.

The study's findings suggest that the SACI should consider utilizing SMAs as valuable tools for improving their companies' marketing efforts, increasing brand awareness, and accessing the information on time. The industry should also consider the use of SMAs in areas such as improving employee performance and reducing costs. Therefore, the SACI should incorporate SMAs in their strategies for competitive advantage, especially in today's digital age. Based on the results of the exploratory factor analysis, the study suggests that SMAs can be categorized into six broad factors: marketing and customer engagement, cost-effectiveness, collaboration and access to information, effective communication, organisational performance, and business growth. Thus, the SACI should consider the potential of SMAs in these categories and tailor their strategies to utilize applications in each category to enhance their overall performance. From the findings of the study, it is recommended that future research should focus on investigating the challenges of implementing SMAs in the SACI. This research can aid in developing a better understanding of how the industry can overcome the challenges and better utilize SMAs for enhanced performance. Additionally, research should focus on exploring the potential of other emerging technologies, such as artificial intelligence, blockchain, and the internet of things in the SACI.

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A Cypriot perspective of the impact of procurement on disputes

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Abstract
No attempts have been made to resolve or analyse the key factors that cause disputes in the Cypriot construction sector and how these causes differ across procurement options. This informed a study to investigate the frequency and factors that cause disputes in Cyprus when the traditional and 'Design & Build' (D&B) procurement options are used. The study used a deductive, quantitative approach and a questionnaire survey to collect primary data from 40 construction professionals. The key causes of disputes in Cyprus were identified following the use of inferential statistics to analyse the primary data obtained. The causes of disputes were similar between the two procurement options; however 'Incomplete Design' showed a statistically significant difference between the median responses of the respondents. Also, the grouped responses of the frequency of disputes showed a difference between the two types of procurement. Most respondents agreed that there was a high level of difficulty in addressing disputes in D&B in relative comparison to traditional procurement. The need to minimise disputes was highlighted as many of its causes make their probability of occurrence to be quite high.

Keywords
Procurement, Disputes, Comparative analysis, Construction projects, Construction in Cyprus.

1. Introduction

Disputes occur between contractors and clients in the course of construction contracts and some of these can be intricate and complex (Dangrochiya et al., 2015; Gunduz & Yahya, 2018). Disputes can undermine project success if not curtailed or managed well. Some attributes concerning the causes of disputes and project success can be mapped, as in Figure 1.

Construction procurement is a functional and contractual framework for connecting and organizing project members all through the construction procedure in a precise extraordinary structure (Tiwari, Chan & Mubarak, 2018). Procurement includes the procedure of creating, managing, and satisfying contracts (International Organization for Standardization (ISO), 2010). It facilitates project risk allocation and management because the option used influences the allocation of responsibilities to the key parties and by extension the cost consequences to them (Osipova & Eriksson, 2011). There are many types of procurement which include the Traditional method, Design & Build (D&B), Management Contracting (Greenhalgh & Squires, 2011), Construction Management (Donohoe & Brooks, 2007), Integrated Project Insurance Procurement (IPI) (Pittard & Sell, 2017; Connaughton & Collinge, 2021), On-Call Contracting (Walker & Hampson 2002), Partnering (Ruparathna & Hewage, 2015) and Public-Private Partnerships (Oyegoke et al., 2009. Procurement can be Cost-led (Cabinet Office, 2014), Two-Stage Open Book (Pittard & Sell, 2017) or Measured-term method (Griffith, 1992).

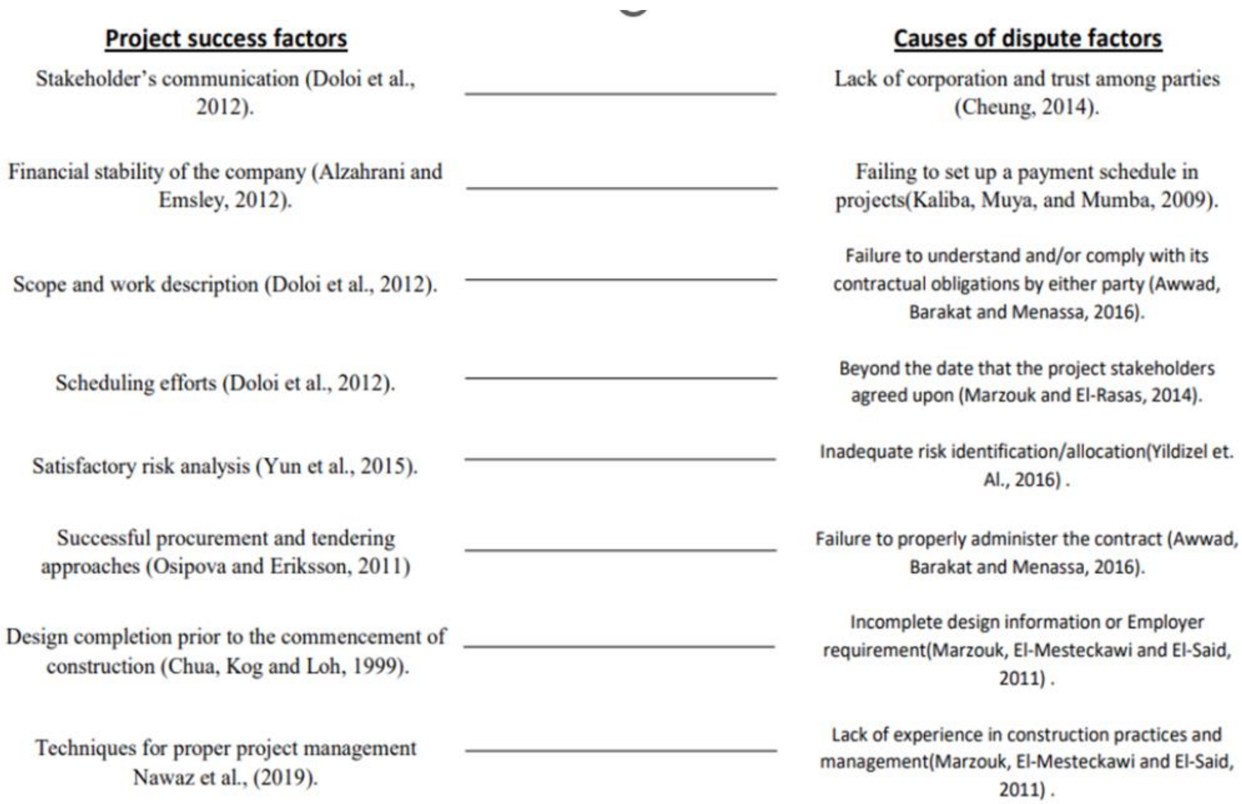

Figure 1. Correlation between factors of project success and factors of causes of dispute.

The D&B and traditional procurement options appear to be used more frequently in construction projects. Meanwhile, there is ambiguity in the frequency of disputes and factors contributing to disputes under these two procurement options. No attempts have been made to study these aspects in the construction industry of Cyprus where the traditional and D&B procurement options are predominantly used. This research gap led to the formulation of our Problem Statement:

- What key factors cause disputes between clients and contractors in Cyprus, and how do these causes vary between the traditional and D&B forms of procurement?

A study was carried out to research this problem.

Aim and Objectives

The aim of the study was to investigate the prevalence of factors that cause disputes within the traditional and D&B forms of procurement in Cyprus. The objectives included:

- To investigate the factors that cause disputes in projects procured by the traditional and D&B methods in Cyprus.
- To investigate the prevalence of the causes of disputes in both traditional and D&B procurements in Cyprus construction.
- To explore how to eliminate or reduce the causes of disputes in Cypriot construction.

The next section will provide a literature review, after which the methodology employed will be explained. The results obtained will then be presented and discussed before the conclusions are made.

2. Literature Review

2.1 The Traditional Procurement Method

In traditional procurement, the design precedes construction. This approach is less risky to the employer due to its inherent assurance about design and project time and cost prior to construction (Ruparathna & Hewage, 2015). Also, the roles and responsibilities are well comprehended and offer high-quality control opportunity (Love et al., 1998). Competitive tendering in this approach further drives down price (Morledge & Smith, 2013).

The approach is however sequential in nature and thus delays the start of construction (Brook, 2017). The contractor's expertise is not utilised in the design process (Hoppe et al., 2013). While a typical lump sum tender may yield the lowest tender price, it may not yield the lowest final construction cost (El-Sawalhi & El Agha, 2017).

2.2 The Design and Build Procurement Method

D&B is an approach where the contractor is responsible for both the design and construction in the project (Brook, 2017). In this approach, there could be novation of design in the process (Walker & Hampson, 2002). There is also a single point of responsibility, which reduces the administrative work of the client (Rahmani et al., 2017). Akintoye and Fitzgerald (1995) and Saaidin et al. (2016), indicated that D&B allows the employer and contractor to communicate more frequently than in traditional procurement. Fitzgerald (1995) showed that D&B projects tend to continue more smoothly because the design and construction teams will be working together and thus there will be less likelihood of conflict. According to Chan (2000), disputes attributable to discrepancies in project documents, as well as project postponement begin to fade away because the D&B contractor has no one but itself to blame for the flaws.

In D&B, contractors can pay lesser attention to the quality of work and life-cycle costs (Walker & Hampson, 2002). The cost of the project is much more imprecise and hence difficult to assess in D&B especially at the earlier stages (Molenaar & Gransberg, 2001). The parties should ensure that the disadvantages do not outweigh the advantages (Anumba & Evbuomwan, 1997).

2.3 Disputes in Construction Procurement

Disputes occur frequently in the construction industry. However, these may occur only once in a project (Levin, 2016). Figure 2 demonstrates the anatomy of construction disputes. Figure 2 indicates different types, and by extension different sources, of disputes.

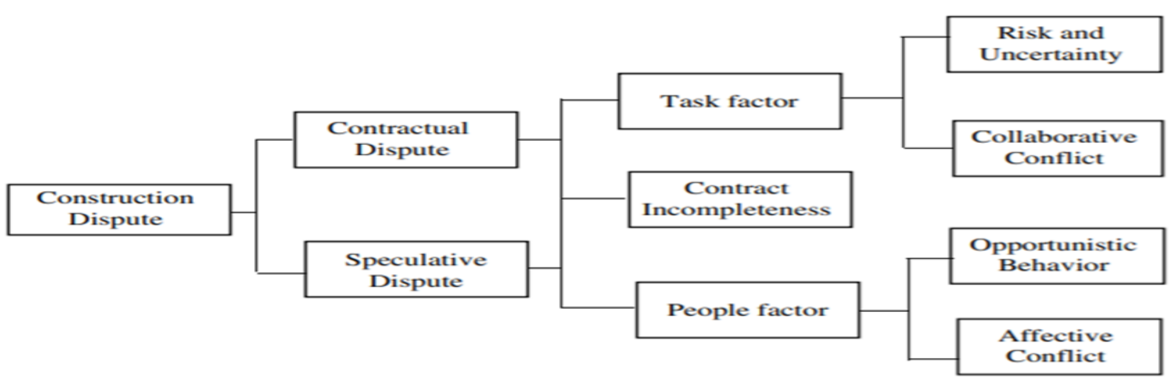

Figure 2: The anatomy of construction disputes (sources: Zhu & Cheung, 2020).

2.4 Causes of Construction Disputes

As stated by Meadow et al. (2018), when there is a variety of experts involved, irregularities among design and construction, project delivery system, and site conditions that encompass the construction industry it frequently leads to conflicts and disputes on the legal obligations and the rights of parties included. Numerous project factors were recognized by Mante et al. (2012) as reasons for disputes in construction, principally not providing the client's purposes in accordance with the cost, time and quality. It is also supported by Zhu and Cheung (2020), that project disputes arise from unbalancing risk, poor quality, timetable delays, power patterns, and a problem with the cost.

According to Arcadis (2018), the infrastructure and public-sector projects are the most contentious, owing to their complexity. Also, changes in circumstances, time, delays, bidding problems, and lack of communication are primary causes of disputes in the construction industry (Jahren & Dammeier, 1990). Nonetheless, Arcadis (2016) determined six causes of disputes: inability to administer the contract, claims that are inadequately deficient and unconfirmed, mistakes and oversights in the contract, fragmentation of design data, parties neglecting to comprehend or conform to their commitments and an inability to proceed with interim payment on augmentation of time and pay.

According to Ismail et al., (2010), there is a high frequency of disputes in the construction industry due to the lack of risk allocation and management. As maintained by Al-Momani (2000), disputes stem from assertions that work was performed outside of the scope of the contract. It is very critical to maintain constancy in the contract, as it minimizes subsequent interpretation disputes (Ismail et al., 2010). Awwad et al., (2016) divided the reasons for disputes into three categories: managerial factors, contractual factors, and civil factors. Illankoon et al., (2019) on their part divided the reasons for disputes into administrative aspects, external aspects, and individual aspects.

Problem Identification/Statement

The above sections were based on evidence from various countries, but data from Cyprus was not found by the researchers. Hence, the main research question formulated was: ***how frequent do disputes materialise in Cyprus and what are the different factors causing these in traditional and D&B procurement?***

3. Methodology

Some of our research objectives were value-neutral and others value-laden. These philosophical opinions informed the adoption of the deductive approach; hence the study involved quantitative data collection and analysis. The survey strategy is regularly used in a deductive approach (Fellows & Liu, 2015) and was thus adopted in our study where a questionnaire was used as instrument. Its benefits include the wider reach of participants (Saunders et al., 2009) and flexibility (Karjalian, 2020). The unit of study was the construction industry of Cyprus, which has an expanding number of new, complicated, and expensive projects, and employs cutting-edge expertise and procedures to deliver creative buildings (Emilianides, 2021). The researchers were granted ethical approval by the School of Architecture and Built Environment of the University of Wolverhampton.

Non-probability sampling was used where 250 questionnaires were sent out by email and 40 responses were obtained, representing a response rate of 16%. The demographic questions obtained nominal categorical data while the rest of the questionnaire collected ordinal data. The Chi-Squared test of independence was adopted as a statistical hypothesis test to determine whether two categorical or nominal variables were likely related or not (Hittner, 2012). The Wilcoxon Signed Rank test and logistic Regression were further used to determine 'if samples came from the same distribution' (McKight & Najab, 2010).

The respondents consisted of 35 males and 5 females; 11 civil engineers, 10 quantity surveyors, 5 architects, 3 land surveyors, 2 contractors, 2 electrical engineers and 7 from other disciplines. Thirty seven of the respondents had a degree qualification. On face value, the respondents can answer the questions adequately and provide valid responses.

4. Results

Disputes develop often in both the traditional and D&B procurements. The respondents rated the frequency of these disputes as: very frequently (17.5%), frequently (35%), occasionally (40%) and rarely (7.5%). These ratings were exactly the same for both procurements. The respondents ranked the underlying causes of disputes as follows:

1. Lack of Interpersonal Relationship Among Professionals
2. Incomplete Design Information
3. Lack of Corporation and Trust Amongst Parties
4. Failing to Setup a Payment Schedule in Projects
5. Failure to Properly Administer the Contract
6. Inadequate Risk Identification
7. Lack of Experience in Construction Management
8. Lack of Client Satisfaction
9. Beyond the Date that Project Stakeholders Agree Upon
10. Inadequate Stakeholders Agree Upon

This ranking was statistically the same for both the traditional and D&B procurement methods.

4.1 Modelling Dispute

Since the dependent variable was nominal, in nature, then the most appropriate model to use was the logistic regression model. However, the simple logistic model can only have a binary variable as its dependent variable. Therefore, the four responses to the question on how frequently disputes arise where split into two groups; the first group contained the people who thought that disputes arose frequently or very frequently, and the second group contained the people who felt that disputes arose occasionally or rarely.

Since the dependent variable, for both methods of procurement, has been converted to a binary variable then the model could be stated as (following Wooldridge, 2015)):

$$P(y_i = 1|\boldsymbol{x}) = G(\beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k)$$
$$= G(\beta_0 + \boldsymbol{x\beta})$$

Where G is function taking value strictly between zero and one: 0<G(z)<1, ∀ real numbers z. This function is the logistic function which takes the form:

$$G(z) = \frac{e^z}{(1 + e^z)}$$

Combining these two equations would restate the logistic regression model as:

$$P(y_i = 1|\boldsymbol{x}) = \frac{e^{(\beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k)}}{1 + e^{(\beta_0 + \beta_1 x_1 + \cdots + \beta_k x_k)}}$$

Where:

- P(y=1|x) is the probability that the respondent will state that disputes rise frequently given different factors.
- e is the exponential function and β_i for i = 1, 2, …, k are parameters to be estimated.

This equation facilitates the modelling of the probability of respondent *i* moving from one category to another; in our case from frequently observing disputes in a procurement method by considering specific factors.

The estimation of this last equation was done using both a backward and a forward stepwise procedure since the number of independent variables was large. This is because there were five demographic variables (control variables) and ten independent variables. Stepwise regression is a procedure where the inclusion (forward) or exclusion (backward) of an explanatory variable is based on a specific criterion. In this analysis, a p-value of 15% was the criterion for both models.

Based on the regression results, the only factor that was statistically significant regarding the frequency of disputes arising in the traditional method of procurement was ‘the failure to properly administer the contract’. The estimated coefficient was 1 with a standard error of 0.460 and a p-value of less than 5%. This means that for every unit increase in the response of the constructor to the question “Failure to Properly Administer the Contract”, the log odds of choosing “Frequently” increased by 1. For example, moving from strongly disagree (1) to disagree, (2) regarding the aspect of “Failure to Properly Administer the Contract” increased the odds ratio of choosing “Frequently” by 2.717. Similarly, according to the model, the estimated coefficient for Age was negative and statistically significant at the 5% confidence level. The implication is that the log odds of choosing “Frequently” as a response to the question “how frequently do disputes arise in Design and Build methods of procurement” decreased the older the individual was.

Furthermore, for the D&B model, the factor of “Lack of Interpersonal Relationship Among Professionals” was statistically important at the 1% confidence level. The estimated coefficient for this factor was 1.599, which suggests that for every 1 unit increase in the variable, that is moving from e.g. strongly disagree (1) to disagree, 2) the odds ratio of choosing “Frequently” as a response to the question “how frequently do disputes arise in Design and Build methods of procurement” increased by 4.9481.

$$Probability = \frac{odds\ ratio}{1 + odds\ ratio}$$

Further, the estimated probability for “Lack of Interpersonal Relationship Among Professionals” was 0.831 (or 83.1%). That is, when a respondent moved from strongly disagree (1) to disagree, (2) the probability of choosing “Frequently” as a response to the question “how frequently do disputes arise in Design and Build methods of procurement” increased by 83.1%. Similar arguments can be made for the rest of the attributes and their estimated coefficients.

5. Discussion of results

5.1 Factors that cause dispute in project procured by the traditional and D&B methods

Literature identifies several causes of disputes, e.g.:

- Failure to meet the client's needs in terms of cost, time, and quality (Mante et al., 2012).
- Unbalanced risk, poor quality, timetable delays, power patterns, and a cost problem (Zhu & Cheung, 2020),
- Inability to administrate the contract, claims that are inadequately deficient and unconfirmed, mistakes and oversights in the contract, fragmentation of design data, parties neglecting to comprehend or conform to their commitments and inability to proceed with interim payment on augmentation of time and pay (Arcadis, 2016).
- Irregularities in design specifications, incomplete design data and bad quality of design (Abdallah et al., 2019; Meadow et al., 2018).

Our findings align with the views in literature, particularly that ‘Incomplete Design Information’ is a key cause of disputes in construction (Abdallah et al., 2019; Meadow et al., 2018).

5.2 The frequency of the causes of dispute in Cyprus.

The majority of the respondents’ answers agree with literature that unprofessional conducts by contracting parties, irregularities in design and construction, poor delivery of project systems and site conditions are frequent causes of disputes (Meadow et al., 2018). Ismail et al., 2010) reinforces the prevalence of disputes in the construction industry.

However, the respondents who had a higher degree, i.e. Master's (60% of the sample) or Doctorate (5%), indicated that disputes occurred more frequently in D&B than in the traditional method of procurement. This finding contrasts with Mante et al.’s (2012) view that the traditional procurement procedure has a higher number of disputes than D&B owing to inadequate communication, price competition, and fragmentation. This may be the peculiarity of Cyprus and

our notable finding: that disputes occur more in D&B in Cyprus whereas they occur more in the traditional method of procurement in other countries.

There are plausible reasons why disputes could arise in D&B projects e.g. incomplete or vaguely stated requirements by clients can mislead a contractor to deliver what is not wanted. Section 5.3 below alludes to this reason. Further, a change in the requirements of a client mid-way through a project can cause dispute regarding the contractor's associated demand for extra time and or cost. On the other hand, a client's requirements may be clear upfront, but a contractor can opt to deliver a functional (effective) building product but use materials or apply finishing standards that are not top-class. There could be other possibilities, but our research did not investigate further into the specific reasons why disputes in D&B in Cyprus are relatively higher. The two-fold reasons why we could not proceed further in this direction were: 1) time constrained us, and 2) we did not expect to discover more disputes in D&B and did not expatiate the study instrument to cover this aspect. We take this **notable finding** as a pointer to further research which we will bear in mind in our future endeavours.

5.3 Elimination or reduction of the causes of dispute.

Disputes in the construction industry are nearly always unavoidable (Blake, 2016). The majority of respondents in our study agreed that the causes of disputes in both the traditional and D&B procurement methods can be reduced. The findings suggest that this reduction can be achieved more in Cyprus in the D&B design method, because of the prevalence of disputes experienced in it. One attribute which the respondents agreed could help reduce disputes is 'clear contract specifications'; Meadow et al. (2018) agree with this opinion.

6. Conclusions

The study found that disputes occur in construction projects in Cyprus, as in other countries. The frequency of occurrence of these disputes tends to be on the high/higher side in Cyprus for both the traditional and D&B procurement. The respondents in the study that had a higher degree of Master's and PhD felt that disputes occurred more frequently in D&B than in the traditional method of procurement. Notwithstanding, 'Incomplete Design Information' was particularly noted by all respondents as a major cause of disputes in Cyprus.

The study established that addressing disputes is difficult, and relatively more difficult in D&B than the traditional mode of procurement. However, the majority of respondents agreed that the causes of disputes in both traditional and D&B procurements can be reduced in the Cypriot construction industry. The majority of respondents indicated that the gravity of disputes outweighs their frequency of occurrence.

The hope raised by the findings is that disputes can be minimised. We therefore recommend that further studies and quests should be carried out to explore strategies and tactics to minimise or avoid disputes in construction projects in especially Cyprus. We particularly recommend that a future study should explore why more disputes occur in D&B projects in Cyprus.

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The Identification and Impact of Constraints in the Quality of Construction Projects in Manila, Philippines

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Abstract
Infrastructure development in the Philippines is still not included in the contemporary construction projects being expedited globally. The construction industry in the Philippines specifies the following general construction restrictions: economic, legal, environmental, technical, and social constraints. Therefore, it is crucial to study the Philippines' construction constraints to effectively alleviate it. In this study, a survey of professionals in the construction industry was conducted about their construction experience in the city of Manila focusing on construction constraints. The Likert scale and statistical analyses such as Simple Linear Regression and Multiple Linear Regression were used due to the number of variables in the study. Results show that environmental constraints correlate the highest with quality of construction (0.6288) whereas economic, legal, and technical constraints are seen with moderate correlation (0.4575, 0.5745, and 0.5797, respectively), while social constraint is seen to have the lowest correlation coefficient in the quality of construction (0.39). The study suggests that the actions done in a construction project should be thoroughly checked for its environmental constraints. The researchers recommend that a different statistical method should be utilized, to represent the working population in the construction industry more accurately. To produce more accurate results, the sample size and study's target respondents should be increased. Lastly, the addition of respondents from different fields of engineering should be treated equally to avoid bias in the analysis.

Keywords
Construction Constraints, Philippine Construction, Construction Quality, Simple Linear Regression Analysis, Multiple Linear Regression Analysis

1. Introduction
The current state of construction performance of the Philippines, considering the lack of reliability, safety, and significant improvements, ranks the country at the lower bottom of the World Economic Forum's Global Competitiveness Report (WEF, 2017). Relative to other countries in the Association of Southeast Asian Nations (ASEAN), the quality and quantity of public infrastructure and infrastructure investment are low in the Philippines. With the subpar performance of the country in the construction industry worldwide, the researchers of the study suggest identifying the general construction constraints that affect the deterioration of the country's performance in the infrastructure sector, as well as associating these constraints with its impact on the quality of construction projects. Quality in the construction industry is distinguished as the attainment of the satisfaction of the customer, and the accomplishment of the client's or owner's requirement within a specified budget (Abas et al., 2015). With the critical requirements mentioned that aid in the accomplishment of the project, there lies a need for conducting a study specifically in Manila, the capital of the Philippines. The study's main objective is to identify the main construction constraint and its impact on the quality of construction projects in Manila, Philippines. The study aims to determine the relationship between construction constraints focusing on quality in construction projects. Hence, researchers of the study particularly identify the impact of construction constraints on the quality of construction projects using Linear Regression Analysis, determines the major construction constraint from the five categories: economic, legal, environmental, technical, and social, and provides the importance of determining the major construction constraint. The researchers limit the study to a survey on construction professionals comprising of engineers, architects, contractors, builders, and professors that are aware of numerous constraints evident in Manila projects. Gathering the acquired information, the researchers focus on how to eliminate the construction constraints and itemize the importance of its identification.

2. Methodology

The survey questionnaire was adapted from Bhavsar and Solanki (2020) that was used to collect the response of construction professionals through the Likert Scale. Bhavsar and Solanki (2020) used a five-point Likert Scale as the quality performance indicator where the measurement of the data was specified as 5 – extremely high, 4 – high, 3 – medium, 2 – low, and 1 – exceptionally low. The survey was conducted through Google Forms and was analyzed by using a mixed methodology.

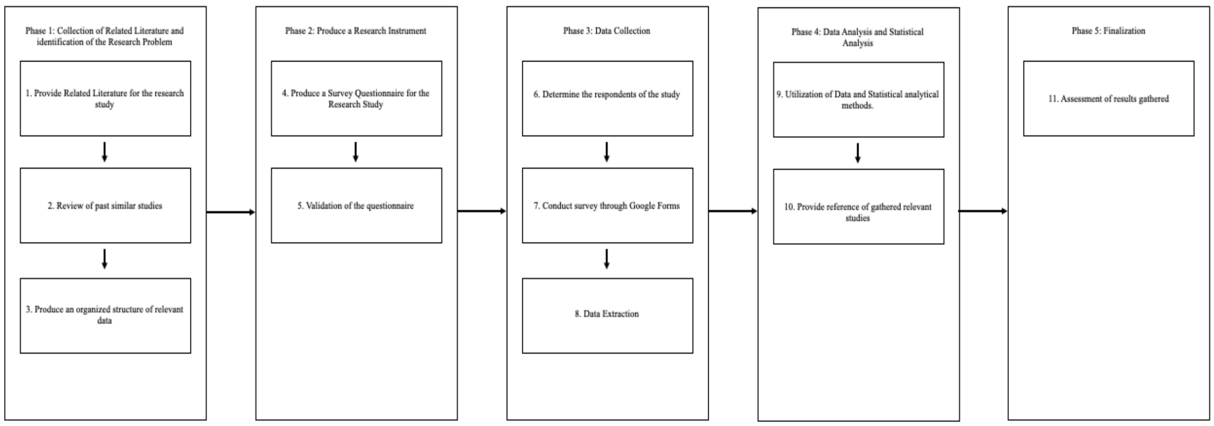

Figure 1. Conceptual Framework in a Flowchart

Using Multiple Linear Regression, the data gathered from the survey questionnaire was interpreted based on the quality performance level chosen by the respondents and was compared to data analyzed in previous studies. The factors affecting each construction constraint were specified as limiting factors. The limiting factors on the quality of construction projects were identified to be the dependent variable (X). Meanwhile, the quality performance level rated by the respondents was identified to be the independent variable (Y).

CONSTRUCTION CONSTRAINTS		QUALITY PERFORMANCE LEVEL				
		1	2	3	4	5
Economic Constraints	Soundness in financing the project by the owner					
	Promising of completion of project					
	Difficulties in obtaining loan from financiers					
	Improper allocation of money to related parties					
Legal Constraints	Difficulties in obtaining work permits					
	Land acquisition					
	Chances of change in drawing/ design					
	Building Regulations					
	Safety Regulations					
	Disputes related to contractual documents					
	Work laws (of the current government)					
	Non-availability of land within city limits					
	NOCs from different departments					
Technical Constraints	Practicability of completing the project in given duration					
	Delay in solving problems					
	Inappropriate project cost estimation					
	Imperfect drawings & details					
	Unavailability of skilled Engineers and Project Managers					
	Established labs (for material testing) present or not at the place of execution					
	Unavailability of storage space					
	Restricted site area					
	Poor condition between different agencies					
	Improve resource levelling					
	Improper power delegation					
	Poor planning & scheduling					
Social Constraints	Politicking (politics)					
	Orthodox beliefs of people					
	Ownership of the problems					
	Media (their honesty & dishonesty)					
	Emotional constraints					
	Inadequate compensation for the land					
Environmental Constraints	Environmental clearance certificate					
	Weather effect on execution activities					
	Air, water, or ground pollution					
	Noise and dust pollution					
	Traffic & transport					
	Topographic & Soil strata					

Figure 2. Types of Construction Constraints using Likert Scale

Multiple Linear Regression

$$y_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 \quad (1)$$

The independent variable (x) is the Construction Constraint where x_1 is Economic Constraint, x_2 is the Legal Constraint, x_3 is the Environmental Constraint, x_4 is the Technical Constraint, and x_5 is the Social Constraint. Meanwhile, the dependent variable (y) is the Quality of Construction Projects. The data was analyzed using Microsoft Excel to identify the R-Square and p-value of the coefficients. These are significant residuals in the Multiple Linear Regression Analysis that was used to recognize the relationship between the independent and dependent variable.

3. Results

3. 1 Demographics of Respondents

PROFESSION	NO. OF RESPONDENTS	PERCENTAGE	AGE RANGE
Civil Engineer (22-62)	31	57%	22-62
Architect (25-48)	7	13%	25-48
Project Manager (37-63)	5	9%	37-63
Production Manager (36)	1	2%	36
Contractor (30-57)	5	9%	30-57
Interior Designer (24)	1	2%	24
Electrical Engineer (29-45)	3	6%	29-45
Senior Construction Manager (36)	1	2%	36

Table 1. Demographic Profile of Respondents

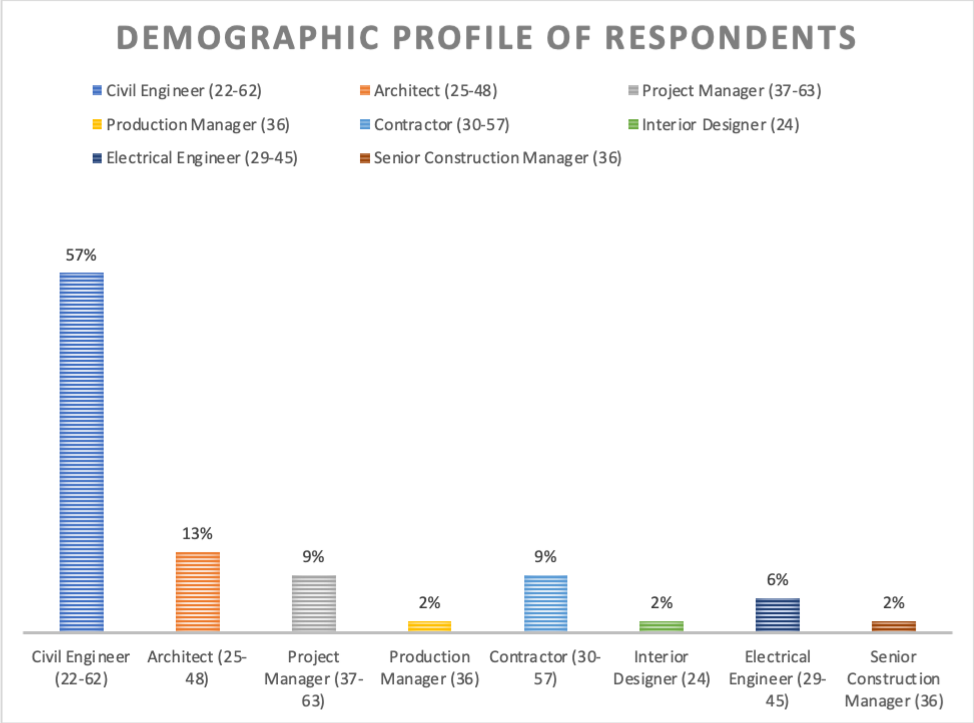

Figure 2. Demographic Profile of Respondents

In Multiple Linear Regression, an independent variable would be deemed significant to the dependent variable, as such each constraint was individually tested to prove for significance and to know which was the most significant. The respondents of the study are specialists from different fields in the construction industry. These are: Civil

Engineers, Architects, Project Managers, Production Managers, Contractors, Interior Designers, Electrical Engineers, and Senior Construction Managers. The respondents are professionals that have construction experience in the City of Manila, Philippines.

3.2 Correlation

CONSTRUCTION CONSTRAINTS	QUALITY
Economic	0.4575086
Legal	0.5744771
Environmental	0.6287575
Technical	0.5796774
Social	0.3943669

Table 1.2 Correlation Coefficients of Construction Constraints

4. Discussion

Correlation in the data quantifies the linear relationship between the dependent variable, Quality of Construction Project, and independent variable, Construction Constraints. It was observed that all coefficient values are positive, indicating that the two variables are directly proportional to each other. BMJ (n.d.) indicated that correlation coefficients ranging from 0.2-0.39 are very weak, 0.4-0.59 are moderate, and 0.6-0.79 are strong. As observed from Figure 1.2, Social Constraint has a correlation coefficient of 0.39, indicating a weak correlation. Meanwhile, Economic, Legal, and Technical Constraint has a correlation coefficient of 0.4575, 0.5745, and 0.5797 respectively, indicating a moderate correlation. Among the correlation coefficients, Environmental Constraint has the highest coefficient with a coefficient of 0.6288.

Simple Linear Regression

ECONOMIC

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.457508579
R Square	0.2093141
Adjusted R Square	0.194108602
Standard Error	0.462145547
Observations	54

LEGAL

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.574477097
R Square	0.330023935
Adjusted R Square	0.317139779
Standard Error	0.425408751
Observations	54

ENVIRONMENTAL

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.628757534
R Square	0.395336036
Adjusted R Square	0.383707883
Standard Error	0.404141844
Observations	54

TECHNICAL

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.57967741
R Square	0.336025899
Adjusted R S	0.323257167
Standard Err	0.423498957
Observation:	54

SOCIAL

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.394366903
R Square	0.155525254
Adjusted R S	0.139285355
Standard Err	0.477606368
Observation:	54

MULTIPLE LINEAR REGRESSION ANALYSIS

Regression Statistics	
Multiple R	0.767980701
R Square	0.589794356
Adjusted R Square	0.547064602
Standard Error	0.346464422
Observations	54

ANOVA

	df	SS	MS	F	Significance F
Regression	5	8.284332232	1.656866446	13.80289596	2.32155E-08
Residual	48	5.7618046	0.120037596		
Total	53	14.04613683			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	1.373300072	0.307643688	4.463930604	4.86693E-05	0.754740981	1.991859164	0.754741	1.991859164
ECONOMIC	0.027064937	0.070595299	0.383381568	0.703129676	-0.114876426	0.169006299	-0.114876	0.169006299
LEGAL	0.139960802	0.061406842	2.279237915	0.027139651	0.016494072	0.263427533	0.016494	0.263427533
ENVIRONMENTAL	0.148825834	0.068019309	2.187993929	0.033570434	0.012063848	0.28558782	0.012064	0.28558782
TECHNICAL	0.130153397	0.062072088	2.09681035	0.041304074	0.005349099	0.254957695	0.005349	0.254957695
SOCIAL	0.16756516	0.063697336	2.630646277	0.011421643	0.039493082	0.295637238	0.039493	0.295637238

Figure 1.3 Simple Linear and Multiple Linear Regression Results for Construction Constraints

The R Square in the data analysis indicates that out of the five (5) construction constraints, the environmental constraint has the highest R Square, indicating that it is the most significant construction constraint in the quality of construction projects in Manila. Furthermore, for the Multiple Linear Regression, the R Square is computed to be 0.58979 which indicates that 58.98% of the Quality Impact in Construction Projects are due to economic, legal, environmental, technical, and social constraints. The statistical significance F is 2.32×10^{-8}. Since the significance value is less than 0.05, it indicates that the model fits the data in the sense that construction constraints can predict the quality of construction projects in Manila. The line fit plots illustrated above in Figure 1.4 reinforces this.

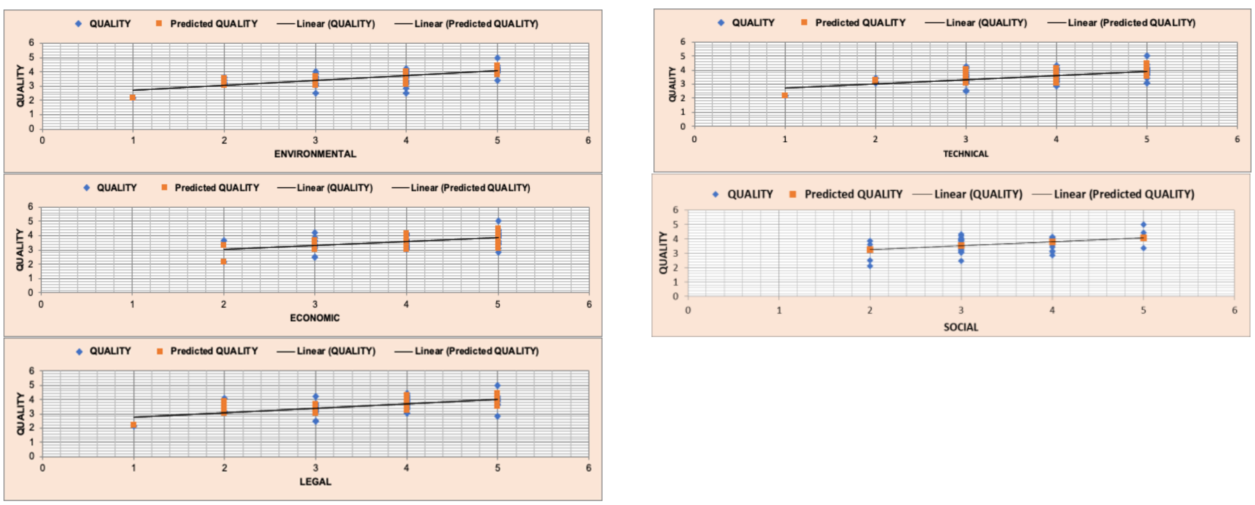

Figure 1.4 Line Fit Plots of Constraints

5. Conclusions

General construction constraints are divided and classified by the construction industry as economic, legal, environmental, technical, and social constraints. Giving the idea that the construction industry is focused on satisfying and accomplishing customer satisfaction and its requirements to a specified budget (Abas et al., 2015). This study identified a relationship between each construction constraint and the quality of construction projects, determined the major construction constraint from the five constraints, and provided the importance of determining the major construction constraint. Moreover, the group formulated a mixed methodology using Linear Regression Analysis to determine the connection between construction constraints to the quality of construction projects. Furthermore, the researchers analyzed the data through Correlation, Simple Linear, and Multiple Linear Regression Analysis designated the relationship between the dependent variable, quality of the construction project, and the independent variable, construction constraint. The correlation indicated that environmental constraint has the highest correlation with a correlation coefficient of 0.6288. This indicates that the correlation between the environmental constraint and the quality of the construction project is extraordinarily strong and directly proportional. The Simple Linear Regression Analysis indicates that the environmental constraint has the highest R Square with a value of 0.3933 denoting that 39.33% of the quality impact in construction projects is due to environmental constraint.

In Multiple Linear Regression Analysis, the p-values of the Legal, Environmental, Technical, and Social are less than 0.05, indicating that there is a significant relationship between these construction constraints to the quality of construction projects in Manila. This indicates that these constraints do affect the quality of construction projects in Manila. Meanwhile, the p-value for economic constraint is greater than 0.05 but having a p-value less than 0.05 using Simple Linear Regression Analysis thus being disregarded from the data analysis. Other statistical methods hold a significant value for environmental constraint hence indicating that it is the major construction constraint for this study. This shows that environmental concerns have a significant impact on the quality of construction projects. Thus, it is necessary to conduct a thorough risk assessment to lessen environmental problems having considerable impact on the project's overall performance for increased customer satisfaction and sturdy and safe construction.

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Drivers of Agent Control Mechanisms in Construction Project Procurement in Nigeria

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Abstract
The efficiency of a procurement system is dependent on the actions of the stakeholders in the system and the best project performance will be obtained when there is a high level of cooperation between all levels of organizational structure. Agency is concerned with the actions and relationships of a principal (a client) and his agents, the professionals and individuals a client designates a level of decision making authority to, in order to perform a task on his behalf. However, to limit divergences from his interest, the principal often establishes appropriate incentives for the agents and incur monitoring costs designed to limit the opportunistic activities of the agents. Therefore, it is important the driving forces of the adoption of agent control mechanisms in construction projects procurement are recognized and comprehended. Thus, this study examines these drivers. A Survey design was adopted. A total number of one hundred and sixty-five (165) questionnaires were administered to construction professionals in Imo State, south eastern Nigeria and one hundred and ten (110) were returned and found suitable for analysis. Collected data was analysed using percentage, mean item score, standard deviation, and Kruskal-Wallis. The findings reveal the drivers of the adoption of agent control mechanisms in construction project procurement in Nigeria which are organization culture as the highest ranked driver, project complexity, top management support, project team trust, cultural background, project status. These findings could inform construction clients in the country on these drivers and encourage them to take significant steps towards putting these drivers in place so as to limit divergences from their interest.

Keywords
Agent control, Construction, Drivers, Nigeria, Procurement.

1. Introduction

Procurement has been a critical role of any government all over the world, based on the fact it is an economy driver. It is a process according to Eriksson & Lind (2015) that is performed in an inter-organisational project-based relationship in which sustainable value is created by the clients and their suppliers and the success of such relationship is dependent on the procurement strategy adopted by the client. However, Ogunsemi (2015) opined that construction project procurements are still plagued with problems of poor productivity and inefficiency. The reason for this might not be unconnected with the high risk and multiparty business nature of the construction industry. Benedict (2017) opined that the fragmentation of processes in the construction industry, which is prone to uncertainty, as well as its network of stakeholders involving different organisations and relationships is just a part of what makes the execution of a project complex. According to Ogbeifun et al (2018), the behaviour and quality of the relationship between these networks of stakeholders (client, consultant, and contractor) influences project progress and success. Ogunsemi (2015) opined that viewing the problems of poor productivity and inefficiency in construction procurement through the lens of the agency theory, the only one thing that is the root cause is the attitude, behaviours, and relationship between the principal and agents involved in the process.

The agency problem describes a situation where the agent behaves dishonestly and performs actions that diverge from the original intentions of the contract if it will benefit him more to do so, usually at the detriment of the project and the principal's welfare. This is a situation that is most often seen in transactions between client and contractors/project managers and contractors/project managers and suppliers in procurement management (Ceric, 2012). When an agent seeks to maximize personal interest, there is often a dwindle in performance that correlates with the performance of the project at hand: unprofessional or underhanded construction practices motivates waste, corruption, and inefficiency, leading to cost and time overruns, low productivity, and increased project costs to correct the inefficiencies of the agent. These are often the reasons behind collusions between agent and principal that become legal cases in court which contribute to the image of the construction industry as being highly litigated (Oyedele, 2016). However, to limit divergences from his interest, the principal can "establish appropriate incentives for the agent and incur monitoring costs designed to limit the opportunistic activities of his agents" (Oteng, 2016). The agency theory opines that it is possible to negotiate optimal strategic alignment of interests between principal and agent to reduce the uncertainty of agents' behaviour (Serrano et al, 2018).

Agent control is concerned with the actions and relationships of a principal (a client) and his agents, the professionals and individuals he designates a level of decision making authority to in order to perform a task on his behalf (Kamau & Rotich, 2015). In the construction sector, this will refer to the relationship between the client and other stakeholders. A client can thus enable different levels of collaboration in a principal-agent relationship using different types of control. The agent control mechanism have made it possible to better construct contract agreements in ways that induce the agent to work in the interest of the principal (Oteng, 2016). The purpose of controls in procurement, therefore, is to account for cost, quality, and timeliness. Having control over agent behaviour regulates the behaviour of the suppliers and service providers, and introduces an environment of cooperation on-site, thereby managing resources and time. However, in a weak institutional system like Nigeria's, the control measures laid down to combat problems of agency have unfortunately crumbled (Nnadi, 2015). Dominant organisational literature proffers three agent control mechanisms and they are market, bureaucratic, and clan control systems. Therefore, it is important the drivers of these agent control mechanisms in construction projects procurement are recognised and comprehended. Thus, this study examines these drivers in the Nigerian construction industry.

2. Materials and Methods

The study took a post-positivist approach in terms of philosophy, employing quantitative research that was carried out using a questionnaire survey. The questionnaire was divided into two segments, with the first segment intended to elicit background data from the respondents. The second segment tried to address the drivers of the identified agent control mechanisms. The respondents, who are construction professionals were requested to rate the significance of the drivers of the identified agent control mechanisms in the Nigerian construction industry using a 5-point Likert scale, with 5 being Strongly significant, 4 being significant, 3 being moderately significant, 2 being slightly significant , and 1 being not significant. The study population were made of qualified construction professionals (engineers, architects, quantity surveyors and construction managers) who are working in Imo State, Nigeria and had at least five years of work experience. Due to time and financial restrictions, convenience sampling was used for the study. One hundred and sixty-five (165) questionnaires were sent out to the construction professionals and one hundred and ten (110) were received and considered appropriate for investigation. Standard deviation, percentages, mean item scores, and Kruskal-Wallis tests as adopted by Otasowie & Oke (2022) were used to analyse the collected data. Using the Cronbach's alpha test, which yielded an alpha value of 0.922, the study validated the questionnaire's reliability. Given that the alpha score is over the cutoff point of 0.6, confirms the questionnaire's high degree of reliability (Tavakol & Dennick, 2011).

3. Results

Professionals from Imo State, Nigeria participated in the survey. The profession with the most involvement (35.3%) is quantity surveyors. Following are engineers (21.6 %), project managers for construction (19.6%), architects (15.7%), and construction managers (7.8%). The majority of these respondents (41.2%) hold master's degrees, while the other levels of education are bachelor, doctoral, and higher diploma degrees, respectively, with 31.4%, 2%, and 25.5%. The total number of respondents had an average working history of 7.6 years, which is a remarkably long period of time in the field. These findings suggest that the study's target respondents, who were construction professionals, were fairly represented and that they had a sufficient degree of education to comprehend the study's questions (Otasowie & Oke, 2022). Also, the answers to these queries were based on a large amount of professional expertise.

Furthermore, the drivers of the agent control mechanisms are shown in Table 1 below, ranging from highest mean to lowest mean. As can be seen, drivers with the same mean were ordered according to how much they deviated from the mean (standard deviation). The mean standard error (SE) is a definition of the standard deviation. The standard deviation reveals what the mean of the observed data was. A modest standard deviation illustrates a situation where most data points are near to the mean, whereas a high standard deviation indicates a data point that deviates much from the mean (Field, 2005). As a result, this was used to rank the drivers with a similar mean. The average of the replies received from each responder makes up the mean for each driver.

The results show organization culture as the highest ranked driver (MIS=4.33, SD = 0.10). This was followed by project complexity (MIS=4.28, SD=0.22); top management support (MIS=4.19, SD =0.28); project team trust (MIS=4.02, SD=0.31); cultural background (MIS=3.98, SD=0.35); project status (MIS= 3.95, SD=0.38); personality (MIS=3.90, SD =0.46); lack of experience (MIS=3.82, SD=0.47); knowledge of past performance (MIS=3.78, SD =0.50); organizational rank (MIS=3.72, SD =0.42); technology (MIS=3.70, SD=0.44); proper governing practices (MIS=3.68, SD=0.45) and ranked last was legal framework (MIS=3.63, SD =0.53).

Table 1. Drivers of Agent Control Mechanisms.

Drivers	Mean	Standard Deviation	Rank
Organization culture	4.3313	0.1016	1
Project complexity	4.2783	0.2217	2
Top management support	4.1850	0.2761	3
Project team trust	4.0165	0.3091	4
Cultural background	3.9748	0.3463	5
Project status	3.9478	0.3803	6
Personality	3.9028	0.4626	7
Lack of experience	3.8236	0.4689	8
Knowledge of past performance	3.7800	0.5010	9
Organizational rank	3.7182	0.4233	10
Technology	3.7002	0.4360	11
Proper governing practices	3.6802	0.4531	12
Legal framework	3.6301	0.5322	13

To compare the responses of the respondents according on their different construction professions, a Kruskal-Walli's test was conducted. It was found that while the responses for some drivers of agent control measures in the Nigerian construction industry, such as organisational culture, top management support, organisational rank, and proper governing practices, do not statistically differ from one another significantly. However, they do differ from one another significantly statistically in the case of other drivers. Table 2 below presents the result.

Table 2. Kruskal-Wallis Test Showing P-Values for Drivers

Drivers	P-Values
Organisation culture	0.083
Project complexity	0.000
Top management support	0.068
Project team trust	0.001

Cultural background	0.000
Project status	0.000
Personality	0.002
Lack of experience	0.001
Knowledge of past performance	0.001
Organisational rank	0.071
Technology	0.000
Proper governing practices	0.054
Legal framework	0.000

4. Discussion

Construction projects are an example of a high risk enterprise that naturally implements and uses control mechanisms, even if people being controlled may not be able to see them. Based on the result above, organisational culture is the first ranked driver of the agent control mechanisms, and the impacts of such a culture are crucial. This was even made clear by the Kruskal-Wallis test conducted. The various construction professionals in the Nigerian construction industry agreed that organisational culture is a significant driver of agent control mechanisms. According to Tuuli et al. (2010), a "rule following culture" is driven by a fear of blame or punishment, which creates an inflexible and predictable culture. The development of congruence between an organisation's and its employees' values is known as organisational culture, and it is linked to "organisational performance" as an organisational capital and core competency (Tan, 2019). The purpose of agent control, according to organisation and management literature, is to guarantee that the actions and choices taken by organisational members are in line with those organisations' goals, objectives, and strategies (Merchant & Stede, 2007; Tuuli et al., 2010). Organisations frequently employ control mechanisms to ensure consistency and uphold company values and principles. This is because values and presumptions influence how organisational members see time, the nature of human activity, and both horizontal and vertical linkages at different organisational levels. Clan, adhocracy, market, and hierarchy are four major cultural orientations that are represented by the values and conventions that organisations choose to express in their cultures in order to balance the needs of many stakeholders (Morgan & Vorhies, 2018). Strong cultures are seen as effective communication tools for informing workers about desired behaviours and organisational goals. As a result, organisational culture is seen to be a key factor in the agent control mechanisms that result in desired performance outcomes. This is as performance results show the extent to which major stakeholders, including clients and construction professionals, have been successful in resolving their conflicting interests.

Furthermore, project complexity is a driver of the agent control mechanisms in the Nigerian construction industry. In fact, it is ranked second based on data collected from the various professionals in the industry. A project may be complicated to complete because of special characteristics like its size, position (both vertically and laterally), technical requirements, large precast components, via ducts' curves, considerable work at height, etc. A project's complexity and originality raise questions about how it will turn out (Artto & Wikstrom, 2005). Considering this complexity, client can thus achieve different levels of collaboration in a principal-agent relationship using different types of control mechanism. Hence, having control over agent behaviour which in turn regulates the behaviour of the suppliers and service providers, and introduces an environment of cooperation on-site, thereby managing resources and time. For example, due to greater uncertainties at the design stage at the pre-contract stage of a project, the agents can be controlled by purchasing design services separately from construction services (design-bid-build) which considerably reduces the likelihood of opportunism owing to asset specificity after the fundamental transformation (Winch, 2001). Also, professional firms can provide a standardized intangibility of the service supplied, i.e., clients do not know what they will get, but they know how it will be achieved due to independently established formal work plans. In the event of unsatisfactory performance, redress is provided through the professional institution which is responsible for regulating the education and practice of its members.

Another driver of the agent control mechanisms in the Nigerian construction industry is top management support. This driver ranked third based on the responses of the various construction professionals. This was also made clear by the Kruskal-Wallis test conducted. The various construction professionals in the Nigerian construction industry agreed that top management support is a significant driver of agent control mechanisms. This involves the expression of a desire to collaborate with other parties to address project issues. It has been shown that projects succeed more frequently when top management are in support of an adopted concept or mechanism (Willumsen et al., 2019). Hence, agent control mechanisms will be a success if the system is supported by senior management of a construction organisation. The management team, and more especially senior management, must work efficiently and be committed to the adoption of agent control systems. The rationale is because in an organisation's ability to achieve its goals and objectives, its top management must be able to enforce the practices and rules that must be applied across the organisation. As a result of this enforcement, staff members will become more conscious of and likely to incorporate these practices into their regular work in an effort to further the objectives of the business. Also, the formalisation of agent control systems will offer more precise recommendations for their deployment across all organisational levels. This proves that an organisation's senior management must be committed for whatever objective it sets to be realised successfully (Williams et al., 2014).

Proper governing practices is one of the ranked drivers of the agent control mechanisms in the Nigerian construction industry. According to Muller & Lecoeuvre (2014), project's goals, how the required resources are acquired, and how progress is tracked are all defined by the governance. While McGarath & Whitty (2015) referred to project governance as a method through which a company oversees, manages, and accepts responsibility for a project. Proper project governance drives the adoption of agent control mechanisms in construction. This is because of its ability to create an avenue for accountability and as such benefits management. Furthermore, for the purpose of recognising and addressing risks in construction projects as they emerge throughout project implementation, project governance provides a systematic structure. An example of proper governance practices that drives agent control mechanisms is the installation of a third party system in projects to facilitate control of transactions. These third parties, the ‘principal-agents’ in the agency cycle, are commonly the architect, the engineer and the quantity surveyor in the construction process. According to Winch (2001), their functions are to verify the satisfactory performance or otherwise of the contract, facilitate negotiations when the contract needs to be renegotiated due to variation of works, and serve as a first line of defense for resolving disputes before they reach the legal system and into adjudication, arbitration, and litigation. Then, the architect or engineer must be satisfied as to the quality of the work performed in accordance with specifications, sign the certificate of completion, as well as approve variations to the specification if necessary. Another aspect of governance is the ability to develop credible commitments between the parties, which usually take the form of various forms of ‘hostage’ circumstances (Winch, 2001) which are essentially techniques to keep an agent committed to his work.

Other critical drivers of agent control mechanisms in the Nigerian construction industry identified from the study include project team trust; cultural background; project status; personality; lack of experience; knowledge of past performance; organizational rank; technology; and legal framework.

5. Conclusions

This study evaluates the drivers of agent control mechanisms in the Nigerian construction industry in a bid to adopt the agent control mechanisms in the country’s construction sector. This is for the purpose of having control over agents’ behaviours, regulate the behaviour of the suppliers and service providers, and introduces an environment of cooperation on-site, thereby managing resources and time. The drivers were discovered after a survey of the available literature, which was then presented to the construction professionals in the country. The results of the study show that the most important driver of agent control mechanisms is organisational culture. Project complexity, top management support, project team trust, and proper governing practices, among others are additional significant drivers. It is necessary to note that the concept behind control strategies therefore is the evaluation of monitoring, task measurement and reward structures in order to address issues of quality and risks in agent service as a result of uncertainty, opportunism, bounded rationality, asset specificity, and transaction frequency. The purpose of control is to motivate, or deter certain agent behaviours for the goal of aligning the interest of the agents with the principal. Therefore, it is imperative that the identified drivers are in place for effective implementation of the control mechanisms. These findings could inform construction clients in the country on these drivers and encourage them to take significant steps towards putting these drivers in place so as to limit divergences from their interest.

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Dwellers' Perception of Choosing 3D-Printed Residential Units Over Conventional in the UAE: A Structural Equation Modeling Approach

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Abstract

Three Dimensional printed residential houses are created with substantial 3D printers with the ability to extrude the building materials through nozzles which eventually build a 3D object at the size and dimension of a residential unit. Unlike the traditional methods of building houses, 3D Printing units consumes less energy in constructing residential units. The construction of these units is energy efficient as it uses low-energy technology that encourages energy sparingly. In the Middle East, the United Arab Emirates has made immense efforts in implementing 3D technologies. The aim of this research is to measure and define the main factors that affect dweller's perception on the 3D printing residential units' adoption. To do so, structural equation modeling was used to measure dwellers' perception and their commitment through selected factor. The selected factors are grouped into four categories which are environmental, social, economic and technological. The main factors that impacted the dwellers' perception includes waste reduction, access to amenities and recreational areas, cost-effective and design customization. Towards perception of selecting 3D printed houses and commitment towards sustainability the results showed a positive impact. The practical implication of the study will aid the construction sector in the decision-making process of 3D printed units implementation.

Keywords

3D Printing, 3D Units, Sustainability, Construction, Dwellers, Residential, SEM, UAE.

1. Introduction

The construction industry is known to be one of the most industries that consumes vast amount of resources and having substantial environmental stresses. It is responsible for nearly 38% of Green House Gases (GHG) emissions, 40% of solid waste, and 12% of potable water (Khan et al., 2021). Moreover, it has been reported by (Klotz et al., 2007) that buildings have consumed 36% of the total energy used, 30% of the raw material used and 12% of potable water consumed in the U.S. Its trail and impact are expected to increase given the fact that urban population is anticipated to represent 68% of the world's total dwellers by 2050 which means more built environment projects, more construction and more usage of concrete (Khan et al., 2021). As a consequence it will have a massive economic, social and environmental impact on the globe, ecological systems, and people concerning housing, transportation and different infrastructure necessities (Khan et al., 2021). Therefore, more efficient, sustainable, and innovative technologies must be established, adopted and applied by the construction industry to meet the needs of the build environment and economic and social circumstances. Such technologies are Building Information technologies (BIM), Automation in Construction, and 3D printing.

3D printing is considered an innovative technology that support the triple bottom line; people, profit and planet and is the main focus of this research. The 3D printing was introduced in 1983 by Charles W. Hull, it is a process by which physical objects are created by adding materials in layers based on a digital model. 3D printing technology in the construction is used in many areas such as in producing construction parts, in architectural models and building projects. 3D printing can bring substantial changes to the construction industry, not only as a methodology but also in terms of productivity improvement. Such productivity improvements are (1) waste reduction, (2) flexibility in design that give the developers flexibility in designing structures that can't be done using manual construction practice, (3) less manpower since it is an automated process and other environmental, economic and constructability-related improvements (Wu et al., 2016).

2. Literature Review

2.1 3D-printing as a sustainable approach

3D printing technology is an approach to fulfill the demand for more sustainable and resource-efficient concrete construction practices. It is an approach that aid in improving carbon footprints of buildings by lessening their embodies and operating energy (Khan et al., 2021). Moreover, it helps to attain improved time and cost management, enabling lean construction, and support sustainability in the building sector (OZTURK, 2018) (Mahadevan et al., 2020). 3D printing is also considered sustainable in terms of material usage, it is an additive approach rather than subtractive, hence less materials are required when compared to traditional processes. The required materials are only placed therefore will save on material consumption, that will provide an optimization of the construction components and reduce the industry's environmental impact (Pessoa et al., 2021). This is because when less waste is produced consequently the CO2 footprint is reduced (Pessoa et al., 2021).

3D printing will make construction more efficient while creating sustainable growth and motivating circularity principles, for example through the usage of recycled and environmentally friendly materials unlike most of the conventional approaches that are unsustainable (Despeisse et al., 2017). This will create new opportunities for employment in construction companies that utilize the use of 3D printing systems in their projects. From an economical point of view, this technology is regarded as a cost effective approach in constructing buildings (Khan et al., 2021). As demonstrated, 3D printing technology tackles the three pillars of sustainability, i.e., economic, environment and social, therefore considered a sustainable approach.

2.2 Dwellers' factors for choosing residential units.

There are numerous factors that gives credit to choosing 3D-printing units over conventional, and these factors can include environmental, economic, technological, and social. From an environmental aspect, as known 3D structures are fabricated directly from a digital model in consecutive layers with less materials, which means it minimizes waste of the costly metals. Besides, the fabricated structure can be recycled once they have reached the end of their useful life leading to reduction in waste consequently having less environmental impact. Another way the 3D printing will result in less waste is that its automated system will lessen the impact of human error on the building process thus waste reduction (Holt et al., 2019; Nematollahi et al., 2017). Related to the environment also, 3D printed units contributes to sustainability through reduction in carbon emission (Abdalla et al., 2021). Moreover, 3D printing processes have been coupled with a cost-effective fabrication process that reduce the energy use, resource demand and CO2 emission (De Schutter et al., 2018). Furthermore, it is reported that 3D printed units enhance the thermal comfort within the building and improves the air quality (De Longueville et al., 2020; Mahadevan et al., 2020).

From a social aspect, socio-economic and socio-demographics are main categories that affect the residential unit buyers when they are searching for units when relocating which suits their needs (Petkar & Macwan, 2018). 3D printing promises several benefits from a social point of view where it creates new jobs and improved productivity and performance in the construction industry (Aghimien et al., 2020; Frearson, 2018). Moreover, 3D printed units when fabricated at site poses less injuries and fatalities compared to conventional construction as reported by (Hager et al., 2016; Madiwale). Even in affordability, 3D units are more affordable compared to units built conventionally (Lojanica et al., 2018).

3D printing technology is economical in terms of cost, materials, and labor reduction, which achieves strong affordability, and environmental in terms of friendly local material usage, which will consequently achieve health aspects with fast achievement and efficiency in the fabrication process (Lojanica et al., 2018). Therefore, it can be emphasized that dweller's perception is an important aspect for the developers to develop residential projects capable of catering the most out of the land while maintaining the required needs and as such the 3-D printed households require those attributes to attract dwellers into accepting such technology. It was found that there are four main dimensions that are correlated to such perceptions. These dimensions are summarized in table 1 below, along with the relevant references from the literature:

Table 1: 3D printing units factors that affects dwellers' perception

Category	***Factors***	***References***
Environment	Waste reduction	(Holt et al., 2019; Nematollahi et al., 2017) (Aghimien et al., 2020; Cole & Baghi, 2022; Siddika et al., 2020),(Petrovic et al., 2011);(Weinstein & Nawara, 2015);(Allouzi et al., 2020), (Elantary et al., 2021);(Madiwale)
	Reduction in carbon emission	(Abdalla et al., 2021; Alkhalidi & Hatuqay, 2020; De Schutter et al., 2018; Khan et al., 2021; Liu et al., 2016; Mahadevan et al., 2020; Puppos, 2021; Schuldt et al., 2021); (Holt et al., 2019);(Wu et al., 2016);(Koslow, 2017);(Sakin & Kiroglu, 2017);(De Longueville et al., 2020);(Elantary et al., 2021)
	Reduction in energy consumption	(He et al., 2020; Puppos, 2021) (Cole & Baghi, 2022; De Schutter et al., 2018; Liu et al., 2016; Mahadevan et al., 2020; Schuldt et al., 2021);(De Longueville et al., 2020)
	Thermal comfort	(He et al., 2020; Mahadevan et al., 2020);(Cui et al., 2022)
	Air Quality	(De Longueville et al., 2020)
	Initiative government support	(Kuan & Chau, 2001);(Lian et al., 2014);(Weller et al., 2015);(Yeh & Chen, 2018);(Mavri et al., 2021)
	Green infrastructure	(De Longueville et al., 2020)
Social	New job creation	(Aghimien et al., 2020; Fonseca, 2018)
	Access to social interaction with neighbors	(Petkar & Macwan, 2018); (Li & Wu, 2013);(Mohd Thas Thaker & Chandra Sakaran, 2016);(Cerin et al., 2013);(Nejad et al., 2021)
	Access to Amenities and recreational locations	(Petkar & Macwan, 2018); (Li & Wu, 2013);(Mohd Thas Thaker & Chandra Sakaran, 2016);(Cerin et al., 2013);(Nejad et al., 2021)
	Security & Privacy	(Ballard, 2005); (Othman et al., 2015);(Cerin et al., 2013)
	Less injuries and fatalities	(Aghimien et al., 2020; Hager et al., 2016; Madiwale; Sakin & Kiroglu, 2017)
	Social Awareness	(Ballard, 2005); (Othman et al., 2015);(Cerin et al., 2013) (Hager et al., 2016; Madiwale; Sakin & Kiroglu, 2017)
Economic	Cost-effective	(Holt et al., 2019) (De Jong & De Bruijn, 2013; Koslow, 2017; Mpofu et al., 2014; Sakin & Kiroglu, 2017) (Mahachi, 2021) (Abdalla et al., 2021; De Schutter et al., 2018; Puppos, 2021; Siddika et al., 2020; Wu et al., 2016); (Sakin & Kiroglu, 2017; Tobi et al., 2018)
	Transportability	(Aghimien et al., 2020; Holt et al., 2019); (Puppos, 2021); (Oberti & Plantamura, 2015; Sakin & Kiroglu, 2017);(Petkar & Macwan, 2018); (Li & Wu, 2013);(Mohd Thas Thaker & Chandra Sakaran, 2016);(Sakin & Kiroglu, 2017)

	Affordability of unit price	(Petkar & Macwan, 2018); (Li & Wu, 2013);(Mohd Thas Thaker & Chandra Sakaran, 2016);(Cerin et al., 2013);(Nejad et al., 2021), (Aghimien et al., 2020; Lojanica et al., 2018) (Mahdi, 2021) (Humaidan et al., 2019) (Coblentz, 2019) (Puppos, 2021)
Technological	Time to complete	(Holt et al., 2019; Mpofu et al., 2014) (Koslow, 2017) (Nematollahi et al., 2017) (De Schutter et al., 2018; Fonseca, 2018) (Cole & Baghi, 2022; Siddika et al., 2020),(Sakin & Kiroglu, 2017)
	Design Customization	(Holt et al., 2019) (Sakin & Kiroglu, 2017) (Mahachi, 2021) (De Schutter et al., 2018; Wu et al., 2016) (Sakin & Kiroglu, 2017; Tay et al., 2017)
	Structural integrity	(Roodman et al., 1995),(Allouzi et al., 2020; Zareiyan & Khoshnevis, 2017),(Tay et al., 2019),(Sakin & Kiroglu, 2017)
	convenient maintenance	(Sakin & Kiroglu, 2017)

3. Methodology

3.1 Geographical location and Data Collection

The research was done in the United Arab Emirates (UAE) and targeted all its residents, UAE citizens and expatriates in all seven emirates. The research methodology was done using SEM. In order to know the dwellers' perception of choosing 3D-printed residential units over conventional ones, a structural equation modelling approach was done. Based on the literature review, 20 factors were found related to the 3D printed units for SEM. The primary phase of the research was a comprehensive literature review, and the secondary phase was obtained through questionnaires. For validation purpose, the questionnaire was piloted, then were refined based on the subject matter experts (SMEs) along with people from different backgrounds to ensure that all questions reflected all dimensions. Moreover, the questionnaire began by introducing the topic of 3D printing units to familiarize the respondents who don't have any previous knowledge about the topic. To do the former, a questionnaire was prepared to measure every factor under each dimension using questionnaire. In the questionnaire, each factor is represented by one question using 5-point Likert scale (1: strongly disagree, 2: disagree, 3: neutral, 4: agree, and 5: strongly agree).

3.2 Data Analysis

The data analysis is divided into three steps, (1) data validation, (2) Confirmatory Factor Analysis (CFA), (3) Structure Equation Modelling (SEM). The following subsection will further elaborate each step.

3.2.1 Data Validation

To test the reliability and the validity of the collected data, the internal consistency of each dimension was measured. The data collected from the questionnaire was validated through assessing the internal consistency of the responses using Cronbach's $\propto$ to measure how each factor is related to one another within the same dimension using Composite Reliability (CR).

3.2.2 Confirmatory Factor Analysis

The role of confirmatory factor analysis is to do a test on findings and arguments to determine their validity using the most common statistical tools, that is, confidence, interference, and significance (Harrington, 2009). To test our measurement model, the standardized covariance matrix of the selected dimensions is analyzed to test the following hypothesis.

3.2.3 Structural Equation Modeling

Structural equation modeling is a statistical tool that is used to analyze structural relationships using multivariate options. This model uses a combination of multiple regression analysis and factor analysis, using them simultaneously to measure latent constructs and measured variables (Kim & Jung, 2016). This research was conducted through SEM, where factors was gathered from literature review and then gathered under four endogenous dimensions which are (1) environment, (2) social, (3) economic, and (4) technology. A Confirmatory Factor Analysis (CFA) was conducted to measure the dimensions using the extracted factors from literature review as explained in the above sub-section followed by SEM to assess the impact of the endogenous dimensions on the dwellers' perception which is the exogenous dimension. To test our hypothetical model, the standardized covariance matrix of all selected dimensions and their factors are analyzed to test the following hypotheses:

H1: There is a significant correlation among the tested dimensions.

H2: Environmental aspect has positive impact on dwellers' perception of choosing 3D-printed residential units over conventional ones.

H3: Social aspect has positive impact on dwellers' perception of choosing 3D-printed residential units over conventional ones.

H4: Economic aspect has positive impact on dwellers' perception of choosing 3D-printed residential units over conventional ones.

H5: Technological aspect has positive impact on dwellers' perception of choosing 3D-printed residential units over conventional ones.

H6: There is a significant correlation between the tested dimensions with the presence of the perception model.

H7: There is a significant impact of the dwellers' perception on their commitment towards sustainability.

4. Results and Discussion

4.1 Results

4.1.1 Demographics

At the data collection stage, the data collected from population of UAE and a sample of 250 respondents answered the distributed survey. The gender distribution was 70% females and 30% males which would provide better understanding as females are mostly utilizing their household units. The age ranges had a lot of variations but mostly were in the range of 25-30 years as approx. 50% of the respondents whereas 18-24 and 31-40 years got approx. 23% and 20% respectively whereas above 40 years old were 6%. In terms of the marital status, it was found that 60% were singles and 37.2% married and 2.8% divorced. For the married couples, the question had to be on the number of occupants in the household and it was observed that 3-5 people got approx. 40% whereas 2 persons had 23%, 6-7 people and above 7 had 19% and 15% respectively. The level of academic education had bachelor's holders of 52.23%, Master's degree with 31.25% whereas the High School diploma holders got 10.71% and PhD degree with 5.80%. Next was the employment status which got approximately 70% full employment, 21% seeking jobs, 5.36% part-time employed and 3.57% retired. The monthly salary was asked later with 43% for more than 20,000 AED, 5,000-10,000 AED got 20%, 11,000-20,000 AED obtained 18% and less than 5,000 AED got 17%. Finally, the nationality of the respondents were 43.30% Emiratis and 56.70% non-Emiratis.

4.1.2 Data Validation Results

The validity and reliability measures for the data collected are shown in table 2 without the exclusion of any insignificant dimensions as the SEM has shown higher reliability from the first run while checking the Cronbach's ∝ value for each dimension. It was noticed from the below table 2 that Cronbach's ∝ and CR values are all above 0.75 whereas the common minimum statistical value for this measurement is 0.7 therefore all the dimensions can remain in the model without exclusion as mentioned earlier.

Table 2: Data validation and CFA estimates.

Dimension	***Codes***	***Correlation with Total***	***Cronbach's ∝***	***CR***	***CFA Standardized Parameter Estimates***	***CFA Standardized Parameter Estimates P-value***
Environmental			**0.813**	**0.810**		
Waste reduction	EWR	0.573			0.6535	<.0001
Reduction in carbon emission	ECE	0.571			0.57617	<.0001
Reduction in energy consumption	EEC	0.527			0.76191	<.0001
Thermal comfort	ETC	0.617			0.58479	<.0001
Air Quality	EAQ	0.484			0.63604	<.0001
Initiative government support	EGS	0.557			0.58346	<.0001
Green infrastructure	EGI	0.521			0.62068	<.0001
Social			**0.819**	**0.813**		
New job creation	SJC	0.509			0.55488	<.0001
Access to social interaction with neighbors	SSI	0.588			0.59487	<.0001
Access to Amenities and recreational locations	SAR	0.645			0.71988	<.0001
Security & Privacy	SSP	0.578			0.66851	<.0001
Less injuries and fatalities	SIF	0.599			0.68659	<.0001
Social Awareness	SSA	0.585			0.67237	<.0001
Economic			**0.765**	**0.766**		
Cost-effective	CCE	0.632			0.78031	<.0001
Transportability	CCT	0.558			0.78178	<.0001
Affordability of unit price	CUP	0.604			0.78278	<.0001
Technology			**0.787**	**0.788**		

Time to complete.	TTC	0.608	0.73324	<.0001
Design Customization	TDC	0.659	0.73062	<.0001
Structural integrity	TSI	0.553	0.63926	<.0001
Convenient maintenance	TCM	0.562	0.65392	<.0001

4.1.3 CFA Results

The CFA results are shown in table 2 where it illustrates that the CFA standardized parameter estimates (loadings) are below 0.7, however, since the values are near or around 0.5, this would be included in this SEM model. Although, some factors are less than 0.5 yet the p-value for each of those factors is nearing 0 thus indicates significance to the SEM model. Furthermore, table 3 illustrates the CFA goodness of fit criteria of the model where it shows that the Standardized Root Mean Square Error is 0.0529 which is lower than the acceptable minimum value of 0.06. Next, the Goodness of Fit Index (GFI) showed a value of 0.8870, Adjusted GFI (AGFI) 0.7504 and Bentler Comparative Fit Index was 0.9145 which are all above 0.80 which supports our earlier conclusion of being significant and relatable to the CFA model. In addition to the CFA model, SAS had generated table 4 which is the CFA-Covariance Matrix Among the criteria. This table illustrates that there is a high correlation between the dimensions through the covariance estimates and the p-value that are <0.001. Therefore, this table 5 is a great associate that proves our hypothesis (H1: There is a significant correlation among the tested dimensions). Moreover, when SEM model was tested the correlation even improved as shown in table 6.

Table 3: CFA goodness of fit criteria.

Criteria	Value
Standardized Root Mean Square Error (SRMSR)	0.0529
Goodness of Fit Index (GFI)	0.8870
Adjusted GFI (AGFI)	0.7504
Bentler Comparative Fit Index	0.9145

Table 4: CFA - Covariance Matrix among the criteria

	Environment	Social	Economy	Technology
Environment		1.02437 <0.001	0.45625 <0.001	0.87535 <0.001
Social			0.59491 <0.001	0.84178 <0.001
Economy				0.65664 <0.001
Technology				

4.1.4 SEM Results

Through the SEM modeling, it was assumed through the literature review that the sustainable dimensions of environmental, social, economic, and technological have a positive correlation with the dweller's perspective to choose 3D printed households. Based on the hypotheses tested which was adopted from the literature review, the initial SEM model was built as shown in figure 2. All factors selected at the beginning was retained in the model and nothing was excluded, therefore the initial model is the final one. In addition, figure 3 illustrates the SEM model that tested H7 (There is a significant impact of the dwellers' perception on their commitment towards sustainability). The goodness of fit for the SEM is shown below in table 5 as the Standardized SRMSR is 0. 0.0546 which is less than the minimal statistical value of 0.06. At the same time, the goodness of fit (GFI) 0.903, Adjusted GFI (AGFI) 0.7938 and

Bentler Comparative Fit Index 0.914 are all above 0.8 which indicates that the model is complying with our literature findings and the data collected from the questionnaire.

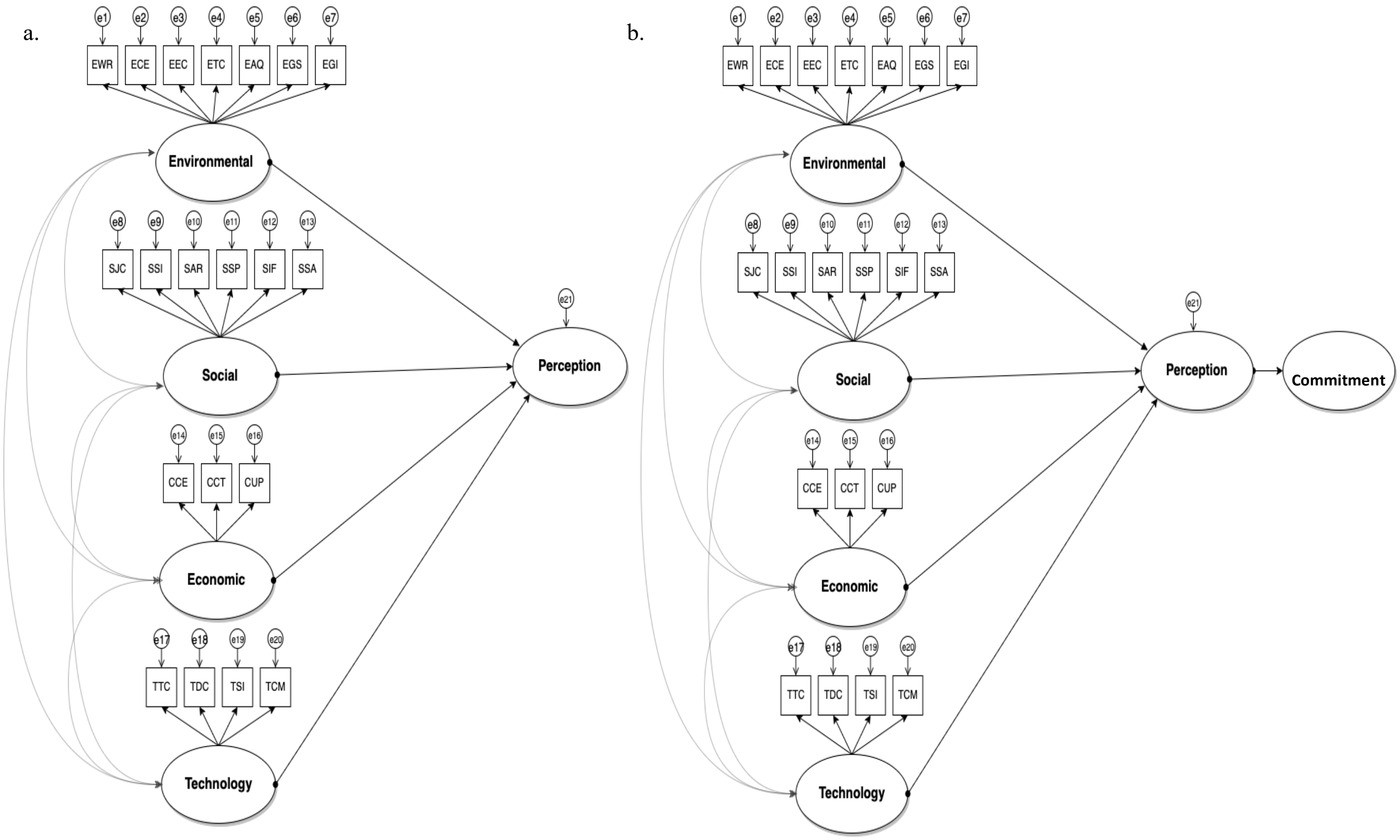

Figure 1: (a) Illustrates the initial SEM model and (b) final SEM model.

Table 5: SEM goodness of fit criteria.

Criteria	Value
Standardized Root Mean Square Error (SRMSR)	0.0546
Goodness of Fit Index (GFI)	0.903
Adjusted GFI (AGFI)	0.7504
Bentler Comparative Fit Index	0.914

Table 6: Covariance Matrix among the criteria.

	Environment	Social	Economy	Technology
Environment		0.93392 <0.001	0.59841 <0.001	0.81588 <0.001
Social			0.68086 <0.001	0.85475 <0.001
Economy				0.61768 <0.001
Technology				

Table 7 illustrates the results of the standardized estimates of all dimensions and their factors with their p-value. This shows that for each hypothesis tested, the parameters are all significant as they show a p-value less than 0.001 with positive correlation. Therefore, the triple bottom line of sustainability; environmental, social, and economic has a positive impact on dwellers' perception to select 3D printed units.

Table 7: SEM path list.

Path	Parameter	Estimate	Standard Error	t-value	p-value
Environment → E1	1	0.56702	0.04941	11.4755	<.0001
Environment → E2	2	0.54530	0.05121	10.6472	<.0001
Environment → E3	3	0.57725	0.04943	11.6788	<.0001
Environment → E4	4	0.67531	0.04233	15.9544	<.0001
Environment → E5	5	0.57058	0.04972	11.4749	<.0001
Environment → E6	6	0.62560	0.04578	13.6665	<.0001
Environment → E7	7	0.62450	0.04586	13.6172	<.0001
Social → S1	8	0.53768	0.05007	10.7385	<.0001
Social → S2	9	0.67945	0.04026	16.8748	<.0001
Social → S3	10	0.71206	0.03741	19.0344	<.0001
Social → S4	11	0.61435	0.04450	13.8047	<.0001
Social → S5	12	0.62212	0.04388	14.1767	<.0001
Social → S6	13	0.65135	0.04155	15.6780	<.0001
Economy → C1	14	0.73454	0.04189	17.5364	<.0001
Economy → C2	15	0.68953	0.04454	15.4826	<.0001
Economy → C3	16	0.74706	0.04121	18.1296	<.0001
Technology → T1	17	0.70709	0.03853	18.3509	<.0001
Technology → T2	18	0.73943	0.03595	20.5693	<.0001
Technology → T3	19	0.66699	0.04171	15.9922	<.0001
Technology → T4	20	0.67351	0.04120	16.3489	<.0001
Perception → Commitment	21	0.44094	0.04740	9.3028	<.0001
Env → Perception	22	0.59794	0.49584	1.2059	0.2279
Social → Perception	23	1.07471	0.61347	1.7519	0.0798
Economic → Perception	24	0.14844	0.13020	1.1400	0.2543
Technology → Perception	25	0.31498	0.18967	1.6607	0.0968

4.2 Discussion

The 3D printing dwellers' perspective have been studied considering the sustainability triple bottom line in addition to technology and was checked through the SEM modeling. Although, the relationship was not immediately identified, where also the literature review has shown the lack of such relationship, However, the SEM and data collected had helped modeling the relationships and the impact of the sustainability dimensions on the dwellers' perspectives which was backed up by the collected data. The CFA has showed the relationship between the sustainability dimensions and has indicated that all of them are significant indicators to the dweller's perspective whereas the SEM has shown the relationship between each dimension and its indicators to impact the dwellers' perception towards 3D printed residential households. Thus, the provided information would assist developers, municipalities, policy makers and dwellers alike when designing or studying the urban settings required for the 3D printed buildings and the perception of the occupants to be their highest priority. Meanwhile, the academic sector can benefit as well from this study to develop more efficient technologies and methodologies to overcome the challenges associated with this technology to satisfy the intended stakeholders. Therefore, many further studies to benefit from this as the technology is still new and that the human factor for the purpose of moving into 3D printed households is to be part of any investment strategy.

5. Conclusions

In conclusion, dwellers' perception was measured towards 3D-printed residential units and their commitment to sustainability. A Structural Equation Modelling (SEM) approach was used to measure the intended latent variables which are social, environment, economic, technological, dwellers' perception and commitment through selected factors from the literature review. It showed that all selected factors are significant in the model and all of them have been retained. Moreover, there is positive impact of dwellers' perception towards selecting 3D-printed units and their commitment towards sustainability through the selected factors. In summary the academic sector can benefit from this study to develop more efficient technologies and methodologies to overcome the challenges associated with this technology to satisfy the targeted stakeholders.

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Benefits of Blockchain Technology in the Prefabricated Construction Industry

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Abstract

The blockchain technology is currently undergoing a global transformation in various industries, including the construction sector. Blockchain technology is required by the construction industry to overcome the present centralized technology's limitations throughout the numerous project life cycles. The ability of the construction sector to take advantage of new technological options to increase productivity has long been criticized. This research looks at the advantages of using blockchain technology in the prefabricated building sector and how it may revolutionize for increased efficiency. In order to collect information from architects, civil engineers, quantity surveyors, mechanical and electrical engineers, construction managers, and project managers, the study used a quantitative survey approach. Using SPSS, the data were evaluated, and the appropriate dispersion measure and inferential statistics were used. The findings showed how blockchain technology might boost efficiency in the construction sector by considering certain project management situations. The study came to the conclusion that, despite being predominantly associated with Bitcoin and other cryptocurrencies, blockchain technology has the potential to provide clarity to the prefabricated building industry's sometimes muddled supply chain.

Keywords

Blockchain, Prefabricated construction, Decentralise, Construction Stakeholders

1. Introduction

The construction sector significantly increases employment across the economy, not simply in the building sector (Kim et al., 2020). The construction industry generates its goods and services using a wide range of inputs from several sources in other industries, and it indirectly helps to create jobs in a number of other industries. The construction has had a challenging several years due to a persistently poor economy, disruptions at construction sites, corruption-related activities, and the sector's reaction to COVID-19. According to Perera et al., (2020) for construction enterprises to remain relevant and competitive, they must take the lead in identifying, appraising, and adopting new technological breakthroughs. Prefabrication applications, which aim to make construction more efficient, effective, productive, and improve the quality of delivered projects in less time than traditional construction methods, have drawn a lot of interest and are gradually coming to be recognized as an effective technological advancement with significant economic, social, and environmental benefits in the construction sector.

Buildings that are constructed using off-site created components fall into the four categories of pre-cut, panelized, modular, and manufactured prefabricated buildings, which are further classified into two types, assembled and unassembled structures (Belle, 2017). Pre-cut construction materials are made from raw materials and processed to be sent in packages or ready-to-assemble kits. They have been machined to a specified size and have been notched and drilled in compliance with standards. Panelized construction is similar to pre-cut manufacturing in that it assembles the component parts into complete panel units in addition to converting raw materials into useable two-dimensional (2D) prefabricated panel pieces. By having whole three-dimensional (3D) building modules produced and preassembled at an offsite facility before being deployed on the construction site, modular building, also known as mobile houses, adds another degree of manufacturing to panelized construction (Prakash & Ambekar, 2020). The use of blockchain technology is anticipated to present a possible possibility for the market adaption of prefabricated buildings due to the intricacy of prefabricated construction. Blockchain is a distributed public ledger of data records of all completed digital events or transactions that is available to all ledger members, according to Wang et al., (2017). The public ledger's every completed transaction is recorded on the blockchain, which is unchangeable and traceable. Due to a verifiable and secure chain of records, blockchain enables authorized parties to access information in the distributed ledger with a high level of trust and transparency (Lanko et al., 2018).

Making sure that payments to stakeholders are made on time is one of the challenges faced by the prefabricated construction sector. Using blockchain technology will improve the accountability and integrity of the payment process by offering secure, traceable payments (Wu et al., 2022). The decentralized and project-based nature of the prefabricated construction sector makes contact between many parties over a long period of time necessary. As a result, coordination problems such as a lack of trust, poor information flow, and supply chain fragmentation occur. The potential advantages of blockchain-based trustworthy transactions are consistent with these coordination problems. Blockchain technology has the potential to improve accountability, transparency, efficiency, and effectiveness for all stakeholders engaged in the prefabricated building process (Wang et al., 2022). Validating why the study aims to assess the benefits of blockchain technology across various prefabricated construction industry stages. Blockchain technology uses a network of servers to maintain a distributed ledger of data, including transactions and agreements that are shared across ledger participants. Although the data is available to a network of users and stored in chronological order, it is decentralized and not controlled by a single entity, such as a bank or government (Azmi et al., 2022). Even if it has consequences for many industries, project management in the prefabricated building industry is made easier by blockchain. Construction projects frequently run into problems, and poor communication between contractors, suppliers, and staff can delay project completion. Applications of blockchain technology are being adopted more often, which will eventually boost the efficiency of the prefabricated construction sector. Thanks to blockchain technology, the prefabricated construction industry now has a great possibility to become more efficient, transparent, productive, and sustainable (Singh, 2020).

According to Hultgren & Pajala, (2018), the detailed structure of blockchain technology is a peer-to-peer distributed ledger that is secure and used to record transactions across many systems. Only by attaching a new block to the one before the contents of the blockchain may be modified. According to business vernacular, another way to think about it is as a peer-to-peer network resting on top of the internet. This platform enables users to conduct transactions of any sort without the need for a central or credible arbiter. The benefit of blockchain is that once the data has been verified by all nodes, it cannot be changed or removed from the public ledger, giving blockchain its qualities for data security and integrity (Kim et al., 2020). Similar to how the blockchain of Bitcoin operates, which has no central authority and has proven to be incredibly resilient to attacks since its inception in 2009, operates, if one block is changed, the entire chain must also be changed, which cannot be done without the consent of the majority of the network (Teisserenc & Sepasgozar, 2021).

Blockchain creates an audit trail that documents an asset's origins at every stage of its journey, according to Yang et al., (2020), and this helps to provide the proof in economic sectors that deal with fraud and counterfeiting. Data on traceability may also disclose weaknesses in any supply chain because items may be parked on a loading dock while awaiting transportation, which is made possible by blockchain, and provenance information can now be directly sent to customers. Since every network user with permissions can view the same data at once and all transactions are time and date stamped records with immutability, blockchain technology uses a distributed ledger to keep identical records of transactions and data across many websites. This ensures complete transparency. Members get access to the complete transaction history, virtually eliminating the chance of fraud. A virtual currency like Bitcoin is used by blockchain, also known as distributed ledger technology, to build secure, private networks where transactions may be made and records kept (Figueiredo et al., 2022). Since these networks are totally transparent and work as trust circles, every member of a private network has their own password, just like any private network does, and every member of the group can see every transaction and the person who approved it. All transactions must input these passcodes to be permitted, and full of them are logged and made publicly available to everyone in the group. Cryptography is used to ensure all payment security and transaction protection. According to (Alnahari & Ariaratnam, 2022), transactions may even be automated with the use of smart contracts, increasing your efficiency and quickening the process even more. Smart contracts reduce the need for human intervention and rely less on third parties to verify that a contract's terms have been followed since the next stage in a transaction or process is automatically triggered whenever pre-specified conditions are met.

Smart contracts may formalize trust between businesses and promote effective cooperation by offering tamper-proof storage, workflow and rule automation, and decentralized identity provision. According to Kiu et al., (2022), blockchain technology in procurement provides transparency throughout the entire supply chain lifecycle because it has the capacity to keep track of every transaction that has ever occurred. With such a high level of transparency, everyone involved in the supply chain is always aware of what is happening.

2. Methods

A structured questionnaire was employed in this study's quantitative technique, and it was distributed to quantity surveyors, architects, engineers, construction managers, and project managers. These specialists were picked from the contracting and consulting industries in both the public and private sectors. These professionals were picked from Gauteng, the province with a large percentage of construction professionals in the nation. Also, due to its strategic location and ability to perform administrative tasks, the province was chosen. Additionally, the province serves as the hub for the provision of high-end services to a variety of sectors, including manufacturing, technical and industrial services, and construction. The target professions for the construction sector were those who were members of the various professional associations in South Africa and other Southern African nations. This safeguard was judged necessary for the survey to ensure that the results truly represented the public's impression of the benefits of implementing robotic technology. The sample size was determined by non-randomly selecting 100 experts. Similar to the closed-end questionnaire used in Adekunle et al., (2022) study that was also divided into two parts. In the first section, the respondents' demographic information, such as their level of education, line of work, and experience—was gathered. The second section's goal was to assess the advantages of employing blockchain. Using a 5-point Likert scale, the benefits of robotic usage were assessed. A response was given to 81 out of the 100 questionnaires that were handed out, or 81% of them. Percentages were utilized to evaluate the benefits of utilizing blockchain technology in pre-fabricated homes when the data was analyzed, and Mean Item Score (MIS) was used to grade the information on the respondents' backgrounds. Additionally, the Kruskal-Wallis test was employed to contrast respondents' viewpoints according to their level of experience. The reliability of the data sets was assessed using the Cronbach's alpha reliability test, which produced a value of 0.805, which indicates a good level of consistency.

3. Results

The research states that 37 percent of responses are clients, and the next highest percentages are project managers (10.1%), architects (9.3%), civil engineers (9.7%), quantity surveyors (18.3%), and project managers (10.1%). 35.5% of respondents reported having one to five years of construction-related work experience, and 40.2% reported having six to ten years. Only 5.5% of the population had experience of between 11 and 15 years, compared to 18.8% of respondents who had worked in the construction industry for at least 16 years or more.

Table 1 shows the respondents' ranking of benefits of blockchain technology applications in the prefabricated construction industry. According to the respondents results indicated that the top six ranked benefits were: promote accountability ranked first with (MIS= 4.44; SD=0.665), streamline procurement and supply chain ranked second with (MIS= 4.39; SD=0.712), promote transparency ranked third with (MIS= 4.38; SD=0.675), promote traceability ranked fourth with (MIS=4.37; SD= 0.757), immutable and unalterable record keeping ranked fifth with (MIS= 4.35; SD= 0.703) and promote security of payment transactions ranked sixth with (MIS=4.32; SD=0.714). The middle six ranked stages were: accelerated payment transactions was ranked seventh with (MIS=4.30; SD=0.617), Hinder corruption and fraud ranked eighth with (MIS=4.27; SD=0.812), ease accessibility of all information and transactions ranked ninth with (MIS=4.26; SD=0.642), auditability trace ranked tenth with (MIS=4.24; SD= 0.688), advanced and clear record keeping ranked eleventh with (MIS=4.24; SD= 0.754), enhancing of trust and instantaneous collaboration ranked twelfth with (MIS=4.23; SD=0.812) and smart contracts that are always on track ranked thirteenth with (MIS= 4.20; SD=0.788. The bottom six ranked stages were: time efficient ranked fourteenth with (MIS=4.11; SD=0.792), promote privacy ranked fifteenth with (MIS=3.94; SD= 1.134), keeping track of project work progress ranked sixteenth with (MIS=3.88; SD= 0.884), scalable to any project size ranked seventeenth with (MIS=3.85; SD=0.963), eliminate suspicious and duplicate transactions ranked eighteenth with (MIS=3.48; SD= 1.135) and cost reductions ranked nineteenth with (MIS=3.33; SD= 0.986).

Table 1. Benefits of Blockchain

Benefits	N	Mean Item Score	Std. Deviation	Rank
Promote accountability	84	4.44	0.665	1
Streamline procurement and supply chain	84	4.39	0.712	2

Promote transparency	84	4.38	0.675	3
Promote traceability	84	4.37	0.757	4
Immutable and unalterable record keeping	84	4.35	0.703	5
Promote security of payment transactions	84	4.32	0.714	6
Accelerated payment transactions	84	4.30	0.617	7
Hinder corruption and fraud	84	4.27	0.812	8
Ease accessibility of all information and transactions	84	4.26	0.642	9
Auditability trace	84	4.24	0.688	10
Advanced and clear record keeping	84	4.24	0.754	11
Enhancing of trust and instantaneous collaboration	84	4.23	0.812	12
Smart contracts that are always on track	84	4.20	0.788	13
Time efficient	84	4.11	0.792	14
Promote privacy	84	3.94	1.134	15
Keeping track of project work progress	84	3.88	0.884	16
Scalable to any project size	84	3.85	0.963	17
Eliminate suspicious and duplicate transactions	84	3.48	1.135	18
Cost reductions	84	3.33	0.986	19

4. Discussion

The most notable benefits of blockchain technology applications in the prefabricated construction industry are ranked as: promote accountability, promote transparency, promote traceability, immutable and unalterable record keeping, promote security of payment transactions, accelerate payment transactions, and hinder corruption and fraud. The results were consistent with research by Mohammed et al., (2021) &(Adekunle, Aigbavboa, et al., 2022). According to Perera et al., (2020) research, blockchain will encourage transparency, traceability, and According to Prakash & Ambekar, (2020) study, blockchain uses a distributed ledger in which identical records of transactions and data are kept across numerous sites. This ensures full transparency and traceability because every network user who has the necessary permissions can view the same data simultaneously. Additionally, because all transactions are time and date stamped records with immutability, fraud and corruption are completely eliminated. According to Lanko et al., (2018) research, blockchain technology would increase payment security, speed up transaction times as cryptography ensures that all payments are secure and that transactions are protected. All transactions require passcodes to be permitted, and all of them are recorded and made public to everyone in the group. Also, according to Wang et al., (2017) study, transactions may even be automated with the use of smart contracts, increasing your efficiency and hastening the process even more. The findings diverged from that of the Hultgren & Pajala, (2018) study, which found that blockchain technology will improve trust, instantaneous collaboration, and procurement. Instead, the Alnahari & Ariaratnam, (2022) study found that smart contracts can systematize trust between organizations and enable effective collaboration by providing tamper-proof storage, workflow and rule automation, and decentralized identity provision. The findings also diverged from research published by Kiu et al., (2022), which claimed that blockchain technology will enhance procurement over the whole supply chain lifecycle.

It is crucial to invest time and resources in training and educating the various stakeholders about blockchain technology applications and how it can make their job easy in terms of delivering the project on time, within the specified budget with better accountability and timeliness since the results in comparison with literature reveal that the respondents are aware of the benefits of blockchain technology applications in the prefabricated construction industry.

5. Conclusions

In various industries, blockchain technology has been used. For instance, the electric industry trades power using smart contracts on the blockchain. Additionally, there is ongoing study into the possible uses of blockchain technology in higher education, including the creation of a worldwide network to store student loans, transcripts of schooling, and other things that may be described in code. In addition, a lot of current research focuses on the use of blockchain in the banking, medical records, land transfer, and food supply chain industries. Furthermore, it is anticipated that blockchain technology would help many sectors and industries, including the prefabricated building industry in the near future, as well as governmental administration (such as passport and identity) and the creation of smarter cities. In conclusion, blockchain technology is currently in its experimental stages and is still relatively new to the construction sector. The advantages and possibilities of blockchain use in the construction sector should not be disregarded, though. Benefits of blockchain technology have been found for the prefabricated building sector, and they include contract management, building information modelling (BIM) systems, data risk management, property management, supply chain management, and funding management. Decentralised, autonomous, peer-to-peer, immutable record, and timestamping are the distinctive characteristics of the blockchain application, which also increase work productivity, save time and money, ensure data security, eliminate errors in information transfer and usage, and promote international collaboration in the construction industry. Despite the benefits, a lot more work has to be done before it can be said that blockchain is an essential component of the building and modular construction process.

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The Emerging Constraints in the Implementation of Prefabrication for Public Housing in the Philippines using Principal Component Analysis

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Abstract
The practice of prefabricated construction has been proven effective due to its numerous advantages, such as onsite construction risk reduction, cost-effectiveness, and efficient construction process. Globally, the role of prefabrication is to improve sustainability and the economic aspect of the construction industry. The Philippines is still adapting to prefabrication and needs more studies regarding the constraints in developing prefabrication in the country. Moreover, public housing projects in the Philippines need to be more proficient due to the neglect of the local governments. The main objective of this paper is to identify the limiting factors in implementing prefabrication on mass housing production in the Philippines. Twenty variables contribute to the hindrances of the development of prefabrication gathered through past related studies. A survey questionnaire was distributed among engineers, designers, property managers, and contractors. A total of 52 responses were collected through google forms. Twenty variables were ranked according to their mean scores after an Analysis of Variance (ANOVA) determined no statistically significant differences between the data from the four stakeholders. To reduce the dimensionality, five limiting factors were identified from a Principal Component Analysis (PCA): Knowledge and Experience, Cost, Risk, Industrial Chain, and Social Climate. High Initial Cost was the most influential variable determined by the mean scores. The government should first provide subsidies to encourage production and consumption in the building sector. When this is implemented, it enables the production of more services and goods.

Keywords
Prefabricated Construction, Public Housing, Constraints, Advantages, Philippines

1. Introduction

The prolonged housing crisis is one of the most pressing concerns in the Philippines' construction industry (Oxford Business Group, 2022). The housing backlog is expected to rise to over 22 million units by 2040 if no solution is implemented and given with only 0.74 percent of the budget, as stated by San Jose del Monte City Rep. Florida "Rida" Robes. In addition, Elsie Trinidad from the National Housing Authority said that housing in the Philippines is budget-dictated. Sometimes, it needs to meet the goal since it competes with other priorities and fundamental sectors. With that said, this study will be associated with public housing which the researchers define as a government mass housing production. Moreover, it aims to address this concern by implementing prefabrication as an ideal way to produce mass houses efficiently.

Prefabrication can significantly reduce construction costs, as Gupta et al. (2018) found that prefabrication is a cost-effective and environmentally friendly method that might be used to provide affordable homes. However, despite all promising features, constraints can exist during its initial stages of adoption. In a study by Jiang, et al. (2018), four factors were found: the industrial chain, cost, social climate, attitude, and risk. A survey and semi-interview were conducted among groups; contractors, engineers, developers, designers, property managers, and component producers, and it was discovered that the industrial chain is an essential factor influencing the promotion of prefabrication in China.

In the Philippines, only some types of prefabrication are guaranteed since, in the conventional sense, it needs large amounts of heavy transportation, cranes, and modern infrastructure, which is not primarily available in the country. As a result, the most practical use is prefabricated components, which can be handled without heavy equipment (Schaik, 2016). Prefabrication slowly adapted and evolved, and various developers and construction companies started offering prefab services and houses. Good services available in the country are the CUBO Modular, Bahay Makabayan Modular & Prefab, Prefab Homes PH by Top-Notch Construction, Indigo Prefab House, SmartHouse Philippines, Prefab PH, MyHouse Philippines, WallCrete, and Nest Box Philippines. The mentioned have in common in offering affordable instant installation.

Prefabrication technology and low-cost housing construction exhibit a strong correlation, which justifies integrating them; thus, with the growing need for large-scale affordable housing, prefabricated building presents a significant opportunity to promote (Zhou, et al., 2018). According to Almarwae and Ganiron (2014), prefabricated components may significantly reduce construction costs, resources, and time; thus, prefabricated housing seems to be a practical option for the Philippine government to address the country's high-cost housing need without sacrificing quality. Prefabrication is indeed a sustainable approach that is an ideal solution to provide housing, given that it is cost-effective and provides urgency to build, especially during post-calamities.

However, the adoption of prefabs in the country is still in its initial stage, so it still needs to be widely promoted. Hence, this study tackled the factors that influence the promotion of prefabrication—furthermore identifying the limiting factors that hinder the locals from utilizing the said technology to assist the stakeholders in the construction industry and prefab experts in addressing this issue.

2. Methodology

2.1 Methodological Framework

This study followed a framework consisting of 5 phases: literature review, questionnaire formulation, data collection, data analysis, and result conclusion. This is shown in Figure 1.

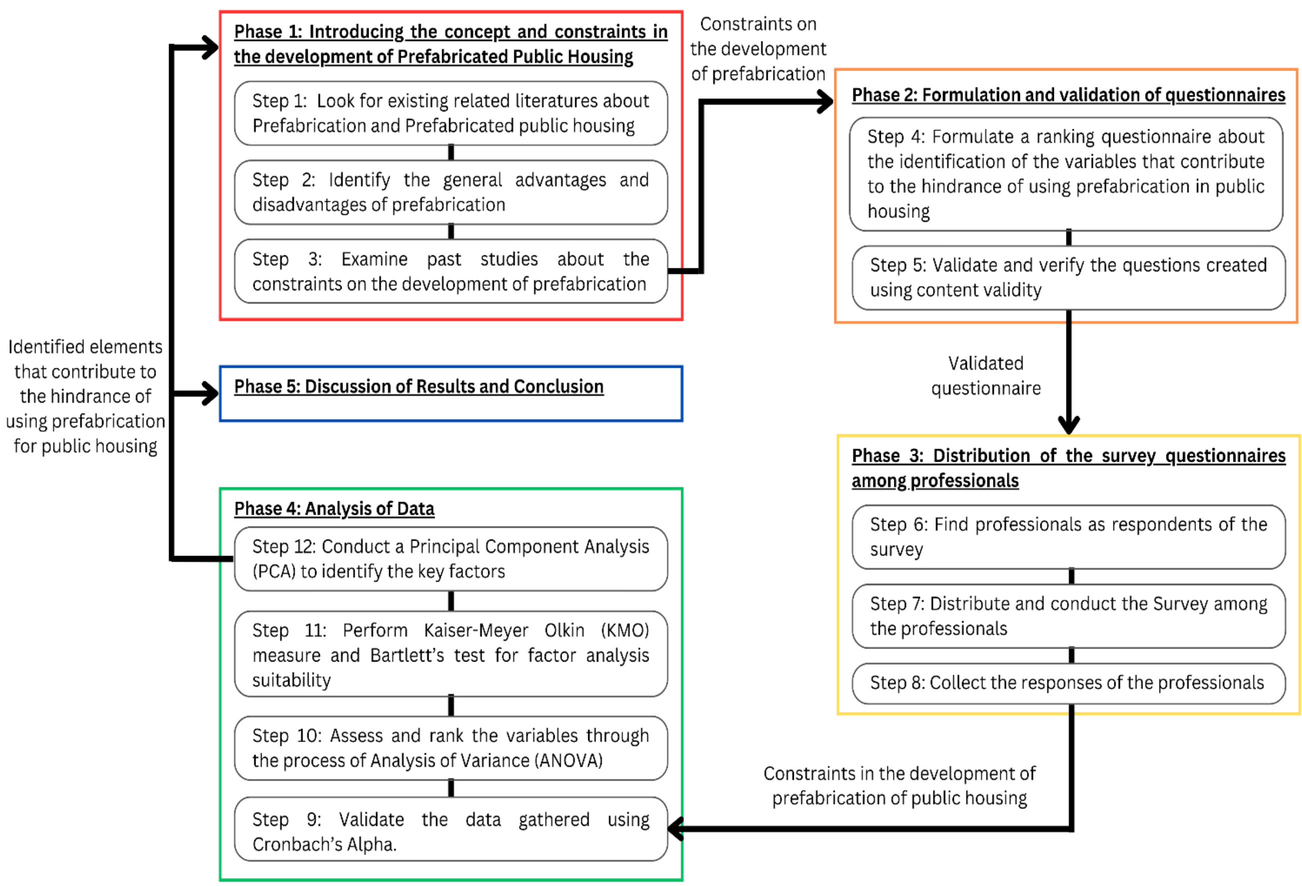

Fig. 1. Methodological Framework

2.2 Statistical Treatments

Statistical treatments were ideal for this study in analyzing and determining the significance of the variables and differences among the stakeholders' groups as the study's respondents. Cronbach's Alpha is used as a reliability test to evaluate the constancy and consistency of the collected data. The range of Cronbach's Alpha is -1 to 1. A negative value suggests that the data is inaccurate. A result between 0.6 and 0.8 is considered satisfactory, while a value between 0.80 and 0.90 indicates that the data obtained from the survey questionnaire is highly reliable.

Once the data were validated, a statistical approach known as Analysis of Variance (ANOVA) was used to enable researchers to evaluate the significance of group differences and the associated methods. The researchers utilized ANOVA to assess whether there was a statistically significant difference between the variable scores from the various groups. This will be confirmed using the resulting ANOVA p-value. An ANOVA p-value of less than 0.05 indicates a statistically significant difference between the groups, while ANOVA p-value values greater than 0.05 means no statistically significant difference between the groups. The researchers also used the mean score approach to evaluate the components' overall relevance. If multiple factors have the same mean score, the factor with the lowest standard deviation (SD) will be ranked higher.

Principal Component Analysis (PCA) is a multivariate statistical analysis approach involving a linear transformation to extract significant variables. The researchers performed PCA since the questionnaire is composed of different measures. Some of them can be related to a specific characteristic. Factor analysis is proposed to determine the variability and correlation of these variables.

Kaiser-Meyer-Olkin (KMO) of Sampling Adequacy and the Bartlett Test of Sphericity are initially applied to the data before performing PCA. Both tests are performed to see if the variables may be used in factor analysis. In addition, this verifies a stand on the research hypothesis.

The researchers used IBM SPSS Statistics 25 in analyzing the data gathered from the respondents to the survey questionnaire. With the help of this tool, tabulated reports, charts, plots of distributions and trends, descriptive statistics, and sophisticated statistical analyses can all be produced using data from different kinds of files. In the case of the researchers, they performed various statistical treatments for this study, such as Cronbach's Alpha for reliability test, ANOVA for identifying the significant difference among various groups of stakeholders, and PCA including KMO and Bartlett's test for factor analysis.

3. Results

3.1 List of Variables

The variables used were initially labeled with codes in the survey questionnaire to simplify the items in the statistical treatments. The list of variables with their codes is presented in Table 1.

Table 1. List of Variables

Code	Variables
V1	Lack of Comprehensive Understanding of Prefabricated Construction
V2	Lack of Relative Policies, Laws, and Standards
V3	Disapproval by the Market
V4	Quality Problems Due to the Excessive Pursuit of Assembly Rate
V5	High Cost Due to Discordant Scale
V6	Unintegrated Industry Chain
V7	Potential Costs Increased Due to Uncertainties
V8	High Initial Cost
V9	Higher Average Cost Compared to Traditional Building
V10	Potential Delays of Manufacturers' Limited Capacity
V11	Lack of Durability, Leakage, and Cracks
V12	Insufficient Construction Capacity
V13	Lack of Well-Developed Technical System
V14	Lack of Research & Development Input
V15	Insufficient Integrated Design Capacity
V16	Low-Level of General Contracting
V17	Lack of Practice and Experience
V18	Lack of New Management Method for Prefabricated Construction
V19	Lack of a Synergetic Information Platform
V20	Long Design Time

3.2 Result of Analysis of Variance (ANOVA)

Before utilizing the collected data for data analysis, the researchers conducted a reliability test to validate the consistency and constancy of the data gathered. Cronbach's Alpha validated the respondents' responses on the 20 variables. From the table, the result shows 0.878, which ranges from 0.8-0.9, which typically implies that the data gathered from the survey questionnaire is immensely reliable.

Table 2 shows a ranking of the mean score of the 20 variables. Two variables (V8 and V17) scored above four and are classified as agreed to be necessary, while the other variables scored above three and were perceived as neutrally necessary. The variable V8, "High Initial cost," has the highest mean score of 4.17 and has a standard deviation of 0.81. Thus, the V8 is perceived by the stakeholders as the main factor influencing the implementation of prefabrication on public housing in the country. Moreover, following the V8 are the V17 (Lack of Practice and Experience), V4 (Quality Problems Due to the Excessive Pursuit of Assembly Rate), V7 (Potential Costs Increased Due to Uncertainties), and V18 (Lack of New Management Method for Prefabricated Construction).

Table 2. ANOVA Results

Variable	Mean					Overall Standard Deviation	Rank	F	P
	3	6	37	6	52				
	Contactors	Designers	Engineer	Property Manager	Overall				
V1	4	3.33	3.97	3.67	3.87	0.95	6	0.887	0.455
V2	3	3.33	4	3.33	3.79	1.016	9	2.059	0.118
V3	3.33	2.5	3.62	3.5	3.46	1.056	18	2.082	0.115
V4	3.33	3.67	3.95	4.17	3.9	0.869	3	0.782	0.51
V5	3.67	3.17	3.92	3	3.71	1.035	13	2.127	0.109
V6	3.67	3.33	3.86	3.83	3.79	0.667	8	1.146	0.34
V7	3.67	4.17	3.95	3.5	3.9	0.955	4	0.58	0.631
V8	3.67	3.67	4.35	3.83	4.17	0.81	1	2.283	0.091
V9	3.67	3.5	3.81	3.17	3.69	1.076	14	0.678	0.57
V10	3.67	3.5	3.97	3.33	3.83	0.985	7	1.022	0.391
V11	4	2.83	3.24	3.33	3.25	1.203	20	0.625	0.602
V12	3.33	3.67	3.54	3.67	3.56	0.978	16	0.1	0.959
V13	3.33	3.67	3.81	3.67	3.75	0.813	10	0.359	0.783
V14	3.33	3.17	3.84	3.5	3.69	1.094	15	0.841	0.478
V15	3	3	3.68	3.33	3.52	1.038	17	1.101	0.358
V16	3.67	3.17	3.86	3.33	3.71	0.776	12	2.071	0.116
V17	3.67	4	4.24	3.83	4.13	0.886	2	0.73	0.539
V18	3.33	3.67	3.95	3.83	3.87	0.817	5	0.651	0.586
V19	3.67	3.67	3.89	3	3.75	0.883	11	1.881	0.145
V20	3	3.83	3.27	2.83	3.27	1.105	19	0.886	0.455

3.3. Result of Principal Component Analysis (PCA)

Kaiser-Meyer-Olkin (KMO) of Sampling Adequacy and the Bartlett Test of Sphericity were performed before beginning the Principal Component Analysis to determine whether the data collected was appropriate for factor analysis. The result shows that the KMO of Sampling Adequacy of the data is 0.681, which can be considered acceptable and exhibits a correlation between variables, and is a satisfactory fit for factor analysis. While there is 0 significance for Bartlett's Test of Sphericity, which implies that the correlation matrix is not an identity matrix, rejecting the null hypothesis and factor analysis is possible.

Principal Component Analysis was then conducted, and there were 6 factors extracted with a 73.95% cumulative variance. Based on the result, V3 has shown the most negligible value in some aspects to be considered significant. Thus, the V3 was eliminated, and another round for PCA was conducted.

Similar to the previous method, the new data set undergoes another KMO measure and Bartlett's test. The resulting KMO measure is 0.71, which is also in a range that is acceptable and shows the correlation among variables. Bartlett's test result has a 0 significance level, indicating that the data are suitable for factor analysis and rejects the null hypothesis.

Table 4 presents the result of a rotated component matrix from the second PCA; 5 factors were extracted from 20 variables with 69.675% of the variance. The items V19, V17,18, V16, and V14 are clustered to Factor 1. For cluster 2, these are the items V9, V8, V10, V5, and V7. While the variables V12, V11, V13, V20, and V15 are clustered for factor 3. The items V1 and V2 are for factor 4. Lastly, the variables V6 andV4 for the fifth factor. The summary of PCA results is presented in Table 5.

Table 3. First Factor Analysis Rotated Component Matrix

Variable	Factors						Communality
	1	2	3	4	5	6	
V17	0.844	0.029	0.161	0.03	0.039	0.079	0.747
V19	0.841	0.204	0.087	-0.057	-0.006	0.016	0.76
V18	0.747	0.304	0.096	0.176	0.15	-0.075	0.719
V16	0.67	0.154	-0.126	0.169	0.221	0.203	0.607
V12	0.15	0.876	0.012	0.05	0.135	0.178	0.843
V11	0.337	0.707	0.245	-0.086	-0.293	0.043	0.768
V13	0.377	0.692	-0.006	0.224	0.073	-0.236	0.732
V20	-0.04	0.664	0.268	-0.275	0.177	0.025	0.622
V15	0.396	0.629	-0.085	0.326	0.416	-0.013	0.84
V19	-0.062	0.05	0.846	0.147	-0.083	-0.092	0.76
V8	0.135	-0.031	0.775	0.244	0.165	0.266	0.777
V10	0.074	0.24	0.675	0.099	0.133	0.288	0.629
V5	0.121	0.11	0.667	0.16	0.463	-0.141	0.732
V7	0.454	0.13	0.538	-0.181	0.155	-0.472	0.793
V1	0.051	0.071	0.168	0.815	0.158	0.045	0.727
V20	0.086	-0.12	0.365	0.78	-0.016	0.148	0.622
V14	0.447	0.376	-0.059	0.456	0.173	-0.402	0.744
V6	0.113	0.098	0.145	-0.056	0.802	-0.049	0.692
V4	0.144	0.085	0.15	0.325	0.711	0.252	0.725
V3	0.374	0.175	0.267	0.178	0.182	0.695	0.79
Eigenvalues	3.495	3.04	2.984	2.076	1.913	1.282	
% of Variance	17.474	15.198	14.92	10.38	9.567	6.409	
Cumulative %	17.474	32.672	47.592	57.975	67.542	73.95	

Table 4. Second Factor Analysis Rotated Component Matrix

Variable	Factors					Communality
	1	2	3	4	5	
V19	0.833	0.098	0.188	-0.068	-0.017	0.744
V17	0.828	0.172	0.014	0.028	0.031	0.717
V18	0.765	0.107	0.294	0.133	0.139	0.72
V16	0.655	-0.105	0.15	0.196	0.227	0.552
V14	0.524	-0.057	0.378	0.346	0.157	0.565
V9	-0.047	0.842	0.043	0.119	-0.097	0.737
V8	0.11	0.786	-0.036	0.28	0.165	0.737
V10	0.048	0.695	0.233	0.153	0.135	0.581
V5	0.148	0.669	0.104	0.095	0.445	0.688
V7	0.501	0.529	0.111	-0.298	0.117	0.646
V12	0.143	0.03	0.875	0.056	0.137	0.809
V11	0.326	0.249	0.696	-0.102	-0.304	0.755
V13	0.424	-0.001	0.69	0.143	0.058	0.68
V20	-0.039	0.285	0.656	-0.265	0.169	0.611
V15	0.426	-0.066	0.632	0.286	0.414	0.839
V1	0.088	0.179	0.085	0.806	0.168	0.725
V2	0.1	0.373	-0.11	0.796	-0.005	0.794
V6	0.13	0.16	0.095	-0.081	0.794	0.689
V4	0.135	0.169	0.091	0.336	0.72	0.687
Eigenvalues	3.499	2.977	2.96	1.984	1.856	
% of Variance	18.417	15.668	15.579	10.442	9.769	
Cumulative %	18.417	34.085	49.664	60.105	69.875	

Table 5. Summary of Results

Factor	Variables
Knowledge and Experience	Lack of a Synergetic Information Platform Lack of Practice and Experience Lack of New Management Method for Prefabricated Construction Low-Level of General Contracting Lack of Research & Development Input
Cost	Higher Average Cost Compared to Traditional Building High Initial cost Potential Delays of Manufacturers' Limited Capacity High Cost Due to Discordant Scale Potential Costs Increased Due to Uncertainties
Risk	Insufficient Construction Capacity Lack of Durability, Leakage, and Cracks Lack of Well-Developed Technical System Long Design Time Insufficient Integrated Design Capacity
Social Climate	Lack of Comprehensive Understanding of Prefabricated Construction Lack of Relative Policies, Laws, and Standards
Industrial Chain	Unintegrated Industry Chain Quality Problems Due to the Excessive Pursuit of Assembly Rate

4. Discussion of Results

Factor 1: Knowledge and Experience

In the Philippines, there has yet to be much-prefabricated construction developed. Several challenges inhibit the industry's continued development in construction, design, technology, scale, experience, and other areas. Current construction companies need to explore alternative frameworks thoroughly and are often cautious about investing significantly in new technology and equipment, resulting in the need for a well-developed system design. Lack of contractors' experience, inflexibility to design changes, and familiarity and knowledge about prefabrication are barriers to construction (Razkenari, M. et al., 2019). The government should consider a systematic classification and integration of previous studies about prefabrication to fully understand and comprehend the impacts on the construction industry in the Philippines.

The Philippines is still in its first phase of implementing new technologies in the construction industry, which needs a competitive market for new construction methods. Most engineers and developers are still choosing traditional construction over new technology. However, this is expected to change as the construction industry develops.

Factor 2: Cost

From the production stages to the transportation stage of prefabrication, prefabricated components are more expensive than traditional construction (Jiang et al., 2020). In the prefabrication process, construction industries should provide storage facilities to keep prefabricated components and sections of any type and size safe from the elements and the weather. Construction personnel must get specific training at prefabricated manufacture and assembly and onsite installation facilities before employing specialized equipment and tools for prefabrication. They must have learned how to handle new products and machinery and coordinate, monitor, and supervise a construction project.

In addition to the high initial cost, training, module transportation to the site, component expenses, and equipment expenses are too expensive. However, cost should be one of many considerations when choosing a building technique. Quality, punctuality, and environmental concerns must all be taken into account.

Factor 3: Risk

Due to insufficient technology that imposes risks on the quality of construction, the prefabricated building sector has remained inappropriate, given the situation in the Philippines. Material strength, unstable joints, and fractures in critical locations are all problems brought on by underdeveloped technology and unskilled workers. Stakeholders may not be interested in prefabricated buildings since resolving these problems could be extremely expensive. Designers should always verify the material strength to ensure it meets standards to mitigate these risks and minimize the problems that may arise during prefabrication and assembly.

The underdeveloped market has also created a need for more prefabricated component manufacturers. Manufacturers typically need help to satisfy growing market demand due to limited production capacity and design for large projects. This raises the possibility of delays that could throw off the schedule for the entire construction project. Prefabrication companies are urged to increase component manufacturing to address the component shortages, which would pave the way for more industry and market collaboration.

Factor 4: Industrial Chain

A well-rounded industrial chain is essential for new construction methods where technology significantly implements new ideas. Due to the lack of comprehensive understanding of the new construction methods, lack of practice and experience, and lack of competence, construction industries often disapprove and stick to their original or traditional ways. In the construction industry, for example, preliminary design for buildings, components, equipment, and installation process these problems in succeeding stages of construction, resulting in cost changes and progress delays.

In an assembly process, prefabricated construction is more complicated than traditional construction, resulting in a lack of construction capacity. Due to design problems, the main structure is complicated to join, making it a top priority for improvement.

Factor 5: Social Climate

Many construction industries still use the onsite construction method in the Philippines, despite knowing that prefabrication has been in the construction market for so long. Numerous construction industries need to gain systematic knowledge and comprehension of prefabricated construction regarding its safety, durability, and the relative policies and standards circling this technology. Additionally, companies involved in the design, manufacturing of modules and components, construction, and assessment of the final product need to familiarize themselves with this prefabrication construction method which shows a lack of comprehensive understanding and a lack to adapt other technologies appropriately.

5. Conclusions

The Philippines has begun slowly adapting the concept of prefabrication technology in construction practices. However, this prefabrication is only applied to limited capacities. According to the related studies, it mostly gathered favorable characteristics that can benefit public housing. This study has collected variables limiting prefabrication usage from related studies for survey questionnaires. 52 respondents participated in the collection of data, and these respondents were composed of different groups of stakeholders such as contractors, designers, engineers, and property managers. The data gathered were validated and treated with statistical treatments. There were no statistical differences according to ANOVA results on the mean scores of the data collected from these groups of stakeholders. According to the mean scores, the top variable was "High Initial Cost," followed by "Lack of Practice and Experience," "Quality Problems Due to the Excessive Pursuit of Assembly Rate," "Potential Costs Increased Due to Uncertainties," and "Lack of New Management Method for Prefabricated Construction." KMO measures and Bartlett's test were applied to the variables, showing that correlation exists among the variables, which rejects the study's null hypothesis and exhibits a satisfactory factor analysis. Thus, these variables were extracted into 5 factors through Principal Component Analysis. The identified five factors are "knowledge and experience," "cost," "risk," "industrial chain," and "social climate." The results of this study are an essential reference for introducing prefabrication in the Philippines' construction industry, specifically in implementing this technology in local public housing projects.

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Exploring the Application of Internet of Things (IoT) For Energy Efficient Buildings in Nigeria. A Review

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Abstract

The global adoption of smart building technologies has been facilitated by the present shift toward Internet of Things (IoT). Despite its benefits, its adoption is still relatively low in developing nations like Nigeria. Therefore, this paper aims to investigate the application of IoT for greatest energy efficiency in buildings, with a greater focus on Nigeria. A review of relevant literature was carried out, to identify the application of IoT in buildings, the current state of IoT application in the Nigerian built environment sector, characteristics and current practices of Nigerian residential buildings regarding energy consumption patterns. A total of 60 papers were reviewed using a narrative and content analysis method. This paper highlights; the lack of smart sustainable building construction in Nigerian and explores the application of IoT for monitoring and visualising the performance of buildings in Nigeria with the aim of optimising efficiency in energy usage. The review has identified research gaps and potentials which can be explored further.

Keywords

Energy efficient buildings, IoT (Internet of Things), Nigeria, Residential Buildings, Sustainable construction, Smart buildings.

1. Introduction

Rapid digitalization has created enormous issues that have raised the energy need (Al-Obaidi et al., 2022). The new era of digitalisation creates new opportunities to boost energy efficiency in the built environment, human health and productivity. One of these opportunities to reduce energy use and accomplish sustainable development goals is the Internet of Things (IoT) (Casini, 2014). When the terms "internet" and "things" are combined, an information and communication technology (ICT) innovation is communicated (Al-Obaidi et al., 2022). Everyday physical items may easily integrate electronics into any form of global physical infrastructure thanks to the concept of interconnected objects (Shammar & Zahary, 2020).

IoT could allow seamless interaction between devices and appliances in intelligent setting, with or without human intervention (Karthick et al., 2021). IoT-connected devices play a crucial role in data collection, processing, and analysis creating a wealth of opportunities for monitoring, managing and improving energy use efficiency in any system (Hakimi et al., 2020). Adopting intelligent IoT technologies can provide network connectivity through which information and services related to physical devices can be exchanged (Al-Obaidi et al., 2022). This may further underline the potential of IoT for preserving energy within the context of buildings. IoT in the built environment is mainly employed to work with data via collection, transmission, storage and analysis (Ashraf, 2021).

IoT applications in smart buildings are growing increasingly popular recently, according to research, as a means to boost energy efficiency and reduce environmental effects (Kumar et al., 2022). Researchers have been drawn to examine IoT and energy efficiency measures because of the profiling of energy consumption in buildings (Xu et al., 2020). Furthermore, the trend towards merging smart buildings with modern detection techniques has begun to provide the groundwork for seeing IoT as an essential component of smart cities (Al-Obaidi et al., 2022). Other studies found that if buildings prioritize excellent system communication, they might consume much less energy (Ceranic et al., 2018; Yahiaoui, 2018). As a result of the advancement in networking, computing, and sensing technologies, the Internet of Things has become an integral part of the design and operation of every intelligent device in the built environment (Ashraf, 2021; Plageras et al., 2018).

Despite the benefits and widespread existence of IoT in numerous fields and construction, little research has been done to investigate the adoption of IoT in construction, particularly in developing nations (Chen et al., 2020). Oke et al. (2020) stated that Nigeria is still lagging in technological advancement because IoT is not extensively employed in the construction industry. To address the enormous environmental challenges and economic concerns that have stifled progressive growth in Nigerian construction, it is clear that adopting smart building technology is critical for development in order to boost innovation and competitiveness (Ejidike et al., 2022). Therefore, this paper aims to investigate the application of IoT (Internet of Things) for the energy efficiency of buildings with a focus on Nigeria. The goal is to highlight the need for IoT application in the Nigerian built environment with the aim proposed.

The study was made to understand, through a general review of the current application of IoT in buildings globally. The paper presents findings from this review on the current state of IoT application in the Nigerian built environment sector, current building style and characteristics of the Nigerian building stock. Furthermore, the study shows recent energy consumption patterns of residential buildings in Nigeria. The research questions addressed are as follows;

RQ1; What are the current trends of IoT application in Buildings globally?

RQ2; What is the current state of IoT application in the Nigerian built environment?

RQ3; What is the current building style and characteristics of Nigerian Buildings?

RQ4; What are the current energy consumption patterns in Nigerian Residential Buildings?

2. Methodology

Grant and Booth (2009) highlighted four common methods of reviewing literature; narrative, rapid, scoping and systematic. The method adopted in this paper is a traditional (narrative) review which identifies what has been accomplished previously, allowing for consolidation, building on previous work, summation, avoiding duplication and identifying omissions or gaps (Grant and Booth, 2009) and makes use of content analysis to examine current trends. According to Stemler (2001) content analysis is useful when looking for trends and patterns in documents. Secondary data was used to perform this study, which is information gathered by someone else for a main purpose (Johnston, 2014). Secondary data gathering and analysis use less time and resources than original data collection and analysis (Johnston, 2014). Secondary information such as publications and journal articles were sourced through scientific databases like; Elsevier Scopus, Google scholar, IEEE and Emerald. The search used the keywords of IOT, sustainable construction, smart buildings, energy efficiency and residential buildings" and Affiliation Country of "Nigeria" were used as prompts in finding literature. 150 papers were identified and scrutinized, but later reduced to 60 papers. By a careful review to eliminate duplicate entries (i.e., referring to the same document), incomplete/incorrect bibliographic details and to exclude non-scholarly/non-peer-reviewed materials.

3. Result and Discussion

3.1 IOT in Buildings.

Balikhina et al. (2018) used the Amazon Web Service IoT platform to create and execute a system architecture for smart power meters to monitor and regulate energy use in residential buildings more effectively. Govindraj et al. (2018) presented an IoT-based management system that links household appliances through the internet and allows customers to operate appliances from any location and at any time using a smart phone. In Marinakis and Doukas (2018) work, an Intelligent energy management in residential settings was proposed via connections between buildings and IoT systems. The system collects and analyses building energy data, then presents the studied data to building occupants in real time. Amaxilatis et al. (2017) developed an IoT based solution to monitor energy usage in educational offices to enhance energy efficiency and human productivity. Luo et al. (2019) proposed that the combination of big data and IoT can be used in energy management systems of office buildings. Rafsanjani and Ghahramani (2019) highlighted a real-time dynamic link between IoT infrastructure information and office-building occupancy-related energy-use trends. Li et al. (2020) used IoT with a solar water heating (SWH) system to improve energy efficiency in a building. The research was carried out at a Singaporean hospital to demonstrate IoT efficiency by monitoring solar levels, operational schedule, water flow, and power consumption. The study found that the SWH with simultaneous control can save electricity by up to 32.9%.

3.2 The Current State of IoT Application in the Nigerian Built Environment.

Nigeria is in West Africa and is bounded to the north by Niger, to the west by Benin, to the east by Cameroon, to the northeast by Chad, and to the south by the Atlantic Ocean. It is between latitude 4 degrees north and 14 degrees north of the equator and longitudinal 3 degrees east and 15 degrees east of the Greenwich meridian (National Commission for Mass Literacy, Adult and Non-Formal Education (NMEC), 2008). It has a land size of 923,768 square kilometers (Aliyu et al., 2018). Nigeria is the most populous country (around 200 million persons) and the largest economy in Africa (International Energy Agency (IEA) et al., 2019). The Nigerian construction industry’s interest in smart buildings has risen dramatically because of technological advancement and the need for increased productivity, efficient energy management and good indoor air quality (Oyewole et al., 2019). Integrating smart building technology into the Nigerian construction sector is crucial, particularly in developing nations dealing with security challenges (Oyewole et al., 2019). Several advantages have been associated with the integration of smart technologies in the Nigerian building sector. For instance, Bandara et al. (2019) indicated that the most prominent benefits of implementing smart building technology are energy conservation, enhanced system performance, life and property security, and occupant health and productivity.

Information on professional awareness for smart buildings is useful in overcoming numerous constraints to smart building techniques in Nigeria. However, there are substantial barriers to the development and investment in smart buildings, particularly in Nigeria and other developing nations. Perhaps, the most significant barrier is the lack of awareness and expertise about smart building concepts (SBCs) in Nigeria (Ejidike et al., 2022). Few researchers have worked on SBCs, while others have focused on building automation, intelligent building, and smart building characteristics in the Nigerian construction sector. Makarfi (2015) in his research, assessed the level of awareness of intelligent buildings among Nigerian architects in the Kaduna metropolitan area and discovered that the awareness of intelligent buildings is lacking among these professionals. In Ogunde et al. (2018) investigation of the integration of building automation systems in Nigerian houses, they revealed a lack of understanding among construction experts, a vital component of SBCs. Oyewole et al. (2019) study looked at smart building awareness and residents' desire for smart building features. They discovered a high level of awareness of smart buildings, with security and safety aspects being the most requested.

Nigerians, the States and Federal Government of Nigeria are uninterested in the modern technology that is taking over every aspect of the life of the citizens in other developed countries (Ayeni, 2020). It is evident that in order for IoT solutions to be deployed across Nigeria, significant improvements to our critical physical infrastructure, such as power and telecommunications, as well as careful amendments to the relevant institutional infrastructure, such as existing regulations respecting data accessibility, security, privacy, anonymity, spectrum licensing, interoperability, and infrastructure improvements, must be carried out by all IoT stakeholders (Uzoma et al., 2021).

Already, governmental and corporate entities in Nigeria are working to develop IoT and provide the groundwork for its adoption. Some of these efforts could be seen in the following initiatives: Indigenous firms such as GRIT systems, Fasmicro and iHabitat manufacture IoT products and solutions (Okunola, 2018). Through the National Information Technology Development Agency (NITDA) and in partnership with Cisco Systems, the federal government built and equipped six IoT laboratories in six federal universities across the countries six geopolitical zones (Uzoma et al., 2021). Nonetheless, Okunola (2018) stated that Nigeria's IoT sector continues to lag behind those of other African nations such as South Africa and Kenya. This was corroborated by Chukwudebe et al. (2021) who stated that as of 2018, the IoT segment of Nigeria’s technological sector was underperforming in comparison to other African markets like Kenya, South Africa, Egypt. Therefore, there is an urgent need to speed up IoT development so that Nigeria will assume a leading role in Africa.

3.3 The Current Building Style and Characteristics of the Nigerian Building Stock.

Nigeria faces a severe shortage of housing stock with up to 16 million of housing deficit (Gesellschaft für Internationale Zusammenarbeit & Nigerian Energy Support Programme (GIZ & NESP), 2014). Rural-urban migration leads to extensive urbanisation, which adds to Nigeria's massive housing deficit (Geissler et al., 2018). It is paramount to provide adequate housing for the masses. Nonetheless, it is apparent that construction activities will undoubtedly put additional strain on the existing energy supply system in the absence of effective regulations promoting energy efficiency and localized renewable energy consumption (Gesellschaft für Internationale Zusammenarbeit & Nigerian Energy Support Programme (GIZ & NESP), 2015). Despite fluctuating or even failing grid energy supply and fuel scarcity, it has been observed that new buildings are largely designed in accordance with what is known as "international style of architecture" (Geissler et al., 2018).

There appears to be a general lack of understanding in Nigeria regarding the direct relationship between building designs and technologies, and their influence on energy efficiency in cutting-edge building design (Geissler et al., 2018). GIZ and NESP (2015) indicated that the approaches for developing energy-efficient buildings are beyond the skills and expertise of majority of architects in Nigeria. Traditional building materials and concepts responding to local climatic conditions are usually considered unprogressive. In contrast, modern materials and building designs from abroad are preferred, leading to designs that consume a large amount of energy, especially for cooling and lighting (GIZ & NESP, 2014). Even though there are a few well-tested and sophisticated solutions available that would fit the climate (e.g., usage of phase change materials, activation of thermal mass), these measures are not well established due to a lack of local precedent (Geissler et al., 2018). Building energy efficiency is a novel idea in Nigeria. To confirm this, the first Building Energy Efficiency Guide (BEEG) for Nigerians was published in 2016, and the Nigerian Building Energy Efficiency Code (BEEC) was introduced in August 2017. As a result, little or no effort has been made in the Nigerian building sector to make building designs more energy efficient. Therefore, incorporating energy-saving techniques in subsequent housing interventions will surely improve people's well-being and the human environment (Ochedi & Taki, 2022).

Assessment of the status quo relies on experts' opinions, case study analyses, and general observations, because neither systematic data collection on the technical characteristics of the building stock nor statistics on actual power usage connected to building types are available (Geissler et al., 2018). There are additional issues affecting baseline data assessment: the existence of suppressed energy demand, electricity theft, and the fact that private generators take over in the event of grid failure (Adamu et al., 2020; Dioha & Emodi, 2019). In Nigeria, the difficulty to acquire data for policy and investment planning is a potentially major issue, as is the practice of so-called estimated billing (households are charged based on estimates rather than actual use due to the lack of meters) (Olaniyan et al., 2018). Olanrewaju and Adegun (2021) corroborated this by saying that among households with electricity connections, tracking residential electricity use is frequently difficult due to privacy issues and the challenge of unmetered households—residences that utilise public utility electricity but have malfunctioning or no meters to record consumption for billing purposes.

3.4 Residential Building Energy Consumption Pattern in Nigeria.

Energy access has been highlighted as the "missing development objective," and its role in supporting economic growth, decreasing poverty, expanding educational reach, and enhancing health has been investigated (Bazilian et al., 2012; Groh, 2014). Energy consumption patterns in Nigeria's economy can be classified as industrial, transportation, commercial, agricultural and residential (Energy Commision of Nigeria (ECN), 2018). The residential sector is critical for the design of sustainable energy systems in developing nations, since it accounts for more than a quarter of non-OECD countries' ultimate electricity consumption, and even up to 60% in countries such as Nigeria (International Energy Agency (IEA), 2017). Also, the expansion of the service sector on the one hand and the rising demand for energy services such as refrigeration, lighting, and cooling in the residential sector on the other hand, urbanisation has led to higher power consumption in residential buildings (Geissler et al., 2018).

The demand for residential electricity in Nigeria grew by roughly 30% (IEA, 2017). This energy is usually consumed in the form of kerosene, liquefied petroleum gas (LPG), electricity and biomass (Energy Commision of Nigeria (ECN), 2014). Nigeria households' main energy service requirements are cooking, lighting, refrigeration, air conditioning, water heating and other electrical appliances such as fans and audio-visuals. Lighting energy requirement in Nigeria households is mainly satisfied by electricity and kerosene. The electrified households concentrated in the urban areas use electricity and the non-electrified households mostly found in the rural areas depend on kerosene for lighting (Dioha, 2018). Other sources of lighting like firewood, candles and dry cell battery torches are also used most especially in the rural areas. However, urban dwellers sometimes resort to kerosene lanterns and dry cell battery torches during blackouts, which is quite common in the country (National Bureau of Statistics (NBS), 2012). The technologies employed for electric lighting are inefficient incandescent bulbs, compact fluorescent lamps (CFLs) and light-emitting diode (LED) bulbs (Dioha, 2018).

Air conditioning and refrigeration services are mostly concentrated in urban areas and energy requirements are completely satisfied by electricity. Most of the air conditioners and refrigerators in use are inefficient types and they are very old. Household cooking takes up to 91% of household energy (Dioha & Emodi, 2019). A survey conducted in urban South-West Nigeria found that the main fuel used for cooking is kerosene (about 90% of the households) while electricity and LPG are used minimally (Ajayi, 2018) mostly in urban areas. The technologies employed in cooking are usually the inefficient traditional three-stone stove system for burning fuelwood, kerosene, and LPG stoves. The continual reliance on fuelwood has led to the clearing of many forests in the country, contributing to climate change (Dioha, 2018). Also, the pollution resulting from burning of biomass for cooking leads to respiratory diseases and has been responsible for about 79000 deaths annually in Nigeria (World Health Organization (WHO), 2007). Most of the rural dwellers find it extremely easy to collect firewood for cooking since it is readily available at no cost.

Water heating is another energy service that consumes a significant amount of energy in the Nigeria household sector (Dioha, 2018). Nigeria has a tropical equatorial climate that is hot for most of the year. Hence only a few people; most especially those in the urban areas use hot water for bathing (Dioha, 2018). The technology commonly used for water heating in Nigeria households is the electric kettle which is concentrated in the electrified urban areas. Many rural dwellers and non-electrified urban dwellers satisfy their hot water needs with the same technologies for cooking (Ezema et al., 2016). Other residential appliances such as ceiling fans, radio, and television consume significant amounts of energy and are mainly inefficient types (Energy Commision of Nigeria (ECN) et al., 2013). These electrical appliances are usually owned by electrified households (Dioha & Emodi, 2019). Ownership also depends on income as this can be observed in the urban-rural ownership dichotomy in the country (Dioha, 2018).

4. Gap and Future Research Direction

Gap No.1*:* Al-Obaidi et al. (2022) undertook a study with the aim of providing an extensive review of IoT applications for energy savings in buildings and cities, they highlighted the fact recent studies deployed IoT sensors or IoT-based prototype systems for both building monitoring and visualising associated data contributing toward energy efficiency and users or facility managers' adaptive responses to save energy. The context of the studies includes the USA, Europe, UK, India, Korea, China, Mexico, Canada, Turkey and Taiwan with certain types of climates. Given the growth and use of IoT technology, the research found a lack of sufficient studies on IoT applications for monitoring and visualising building performance throughout the rest of the world. Chen et al. (2020) claimed in their submission that the readiness of practitioners in the construction sector of developing countries to incorporate IoT applications was not particularly noteworthy. Smart building technology adoption is crucial to tackling the significant problem associated with the low rate of productivity, delay in construction time, inadequate awareness of technological advances and environmental challenges that impede growth in developing nations (Adeosun & Oke, 2022; Indrawati et al., 2017; Oyewole et al., 2019).

Gap No.2*:* Ogidiaka et al. (2017) stated that in Nigeria, the usage of the IoT in different organizations revealed the non-existence of IoT in research, planning and early stages of adoption despite the potential to utilise it. Nigeria still struggles with the infrastructure and innovation gap, not to mention maximising the emerging technologies in providing services like other developed countries (United Nations, 2015; Hajduk, 2016). Ejidike et al. (2022) in his study concluded that construction professionals still need more effort to increase the awareness of smart buildings in the construction industry to deepen the practices in a Nigerian context. They went further to state that the increase in the awareness and adoption of smart building construction would further improve energy efficiency, thereby saving energy costs and protecting the environment from harmful greenhouse gases, protecting lives and property by installing a smart security system that monitors buildings.

Therefore, an empirical study is required to highlight the application of IoT for monitoring and visualising the performance of buildings in Nigeria with the aim of optimising energy efficiency. A critical evaluation to the development of an IOT implementation framework for Nigerian Buildings will form the next stage of an on-going research by the authors.

5. Conclusions

The aim of this study was to investigate the application of IoT (Internet of Things) for the energy efficiency of buildings with a focus on Nigeria. This paper exposed the current trend of IoT applications in buildings globally, current state of IoT application in the Nigerian built environment, current building style and characteristics of the Nigerian building stock, residential energy consumption patterns in Nigeria and the gaps and future research direction.

The review established the growth of IoT in recent years, its benefits and applications to the built environment globally. However, its adoption in developing countries, primarily Nigeria is still lagging in technological advancement because IoT is not widely used in the construction industry.

Therefore, with the aim of achieving improved environmental conditions and mitigating economic barriers that have stood in the way of development within the Nigerian construction sector, it is evident that implementing the practice of IoT in the construction sector more often than before becomes a crucial step to be taken. These technologies show a more advanced approach to energy-efficient usage, which can help the stakeholders of construction projects produce better outcomes regarding its design and operation.

This research is expected to benefit every stakeholder who has a connection with the construction industry, primarily in Nigeria and other developing countries and educators focused on built environment subjects.

The study was limited to academic journal articles and publications sourced from scientific databases described. The analysis and discussions were done solely on secondary data. However, the utilisation of primary data could have produced a far more in-depth understanding of the subject.

For future research, given the rapid evolution of IoT and its applications in the built environment, it would be good to compare the information presented in this study to other future studies on the same issue. Moreover, it is recommended that primary data collection via case studies and questionnaires for a more in-depth analysis could bring solutions that may lead to significant changes and improvements to the technological device and its adoption in the Nigerian built environment.

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A Delphi Exploration of Construction Digitalisation in South Africa

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Abstract
The current technological advancement has rapidly transformed how industries worldwide deliver their products, and the construction industry is not immune to this transformation. However, while the industry in developed countries is gradually picking up with the use of digital technologies in attaining digital transformation, the construction industry in developing countries like South Africa is still lagging in its adoption. Therefore, to promote construction digitalisation within the South African construction industry, this study, through a Delphi approach, unearths the major risks construction organisations will face in their quest for digital transformation. The study also explored the potential of the country's construction industry to be fully digitalised and the demerits of the industry not being digitally transformed. Using appropriate statistical tools, the study found that while the South African construction industry has a high potential to be digitalised, this digital transformation can take a long time to be achieved. Data insecurity and information overload are among the critical risks that organisations seeking digital transformation might have to face. However, should these organisations fail to implement digital strategies in the delivery of their projects, they risk having a lack of competitiveness in the global market and an increase in poor project delivery.

Keywords Construction, Digitalisation, Fourth industrial revolution, South Africa

1. Introduction
In the current industrial revolution, emerging technologies are being used to improve product delivery and customer experience (Schwab, 2017). In construction, digital technologies such as Building information modelling (BIM), Internet of things (IoT), robotics, augment and virtual realities, digital twin, and blockchain technology, among others, are gradually being deployed to improve project delivery. However, the adoption rate of these ubiquitous technologies in developing countries, like South Africa, is still slow compared to the industry's counterparts in developed countries (Aghimien *et al.*, 2021). This slow adoption of beneficial technologies has been noted to be a principal problem in the poor delivery of construction projects that have characterised the construction industry in developing countries (Agarwal *et al.*, 2016). To improve project delivery, adopting digital tools has become obvious. By adopting emerging digital technologies, the construction industry can attain digitalisation and improve client satisfaction (Oke *et al.*, 2018).

Aghimien *et al.* (2019) described construction digitalisation as the adoption of digital technologies in place of human effort to deliver construction services that are satisfactory to the client and for which the organisations can attain a competitive advantage over their competitors. The array of benefits proposed by digitalisation in construction has been immensely discussed in past studies (Aghimien *et al.*, 2021; Delgado *et al.*, 2019; Oke *et al.*, 2018). However, just like every innovation, the move from a traditional approach that appears to be working to a digital approach with several unknowns, can be considered a risky venture for most construction organisations (Vass and Gustavsson, 2017). Past studies on digitalisation in construction have been piecemeal, with each focusing on how diverse digital tools can be applied to solve different problems within the industry. Less emphasis has been placed on the capability of the construction industry to be digitalised. Also, the risk inherent in the digitalisation of construction and the demerits of not being digitalised have gained less attention within the construction digitalisation discourse. Herein lies the knowledge gap.

To promote the digitalisation of the construction industry, particularly in developing countries like South Africa, this study assessed the viability of attaining digital transformation within the South African construction industry. In addition, the study assessed the risk inherent in construction digitalisation and the demerits of not digitalising the construction industry in the country. This was done with a view to preparing the construction organisations for the possible risks involved in the digitalisation process and proposing mitigating measures for addressing these risks should they occur.

2. Construction Digitalisation in South Africa

The concept of digitalisation in the South African construction industry has not been effective as would have been expected for a country with significant potential for digital transformation. A study conducted by Siemens to ascertain the digital maturity of four African countries (Ethiopia, Kenya, Nigeria and South Africa) concluded that South Africa has an established maturity level. This means that the country can be a digital leader in Africa (Dall'Omo, 2017). While the report focused on the manufacturing, energy and transport industries, its finding points to the fact that South Africa has an enabling environment for digitalisation, which can be beneficial for construction organisations. Unfortunately, this digital transformation is yet to happen. Similarly, a survey conducted by Accenture (2019) revealed that while almost all business owners admit that digital technology diffusion into their business can rapidly change their business and service delivery, only very few feel prepared enough to handle this diffusion. This is a pointer that the problem at hand might not be that of awareness but rather that of proper understanding of other factors relating to implementation.

According to Yaghoubi *et al.* (2012), most construction organisations are reluctant to invest in digital tools due to a lack of evidence of return on investment. Taylor and Smith (2000) have also mentioned that, in most cases, it is difficult for these organisations to predict the annual cash flow required for the use of required digital technologies. This implies that organisations risk not getting the expected return on investment, especially when the adopted technologies are not fully utilised. Another crucial issue in the construction digitalisation discourse is the risk of job loss. The resistance to technology adoption within the construction industry has been attributed to the fear that these technologies will replace humans and render people jobless (Mzekandaba and Pazvakav, 2018). The Price Waterhouse Coopers (PwC) reports in 2018 noted that 30% of jobs in South Africa might seize to exist with the advent of emerging technologies. However, Windapo (2016) earlier proposed that instead of pondering on the jobs to be lost, the question should be what types of jobs are these and what else could best replace these jobs. To this end, there have been studies stating that contrary to the popular opinion that technology leads to job loss, the use of pervasive digital tools will open up new markets for new skills and help human improve their skills, particularly in areas of managing these technologies for optimum production (Muro, 2017).

There is also the possibility that once digital tools are adopted, they might not meet the organisation's expectations, particularly in cases where proper needs assessment is not conducted before implementation (Stephenson and Blaza, 2001). This can lead to disappointment and a complete lack of confidence in the use of such technology. More so, it has been noted that technologies are mostly adopted in silos within the construction industry. Each profession adopts the technology better suited to them, and they are rarely willing to share information on the use of such technology (Kane *et al.*, 2015). Aside from this silos use of digital tools, the use of digital technologies poses some data insecurity if not carefully monitored and used. Rubin (2006) noted that the large amount of data produced through digital technologies is susceptible to cyber-attacks due to the interconnectedness of these technologies with the internet. Clearly, attention must be given to ensuring data security in the use of digital tools connected to the internet.

Aside from these envisaged issues, other issues that might emanate as a result of digital uptake in construction organisations include a lack of digitally skilled candidates (Oke *et al.*, 2018), the industry's resistance to technology adoption (Alaghbandrad *et al.*, 2011), fear of infringement of privacy leading to psychological issues (Tatum and Liu, 2017), loss of personal and interactive relations (Zahrandik and Jónsdóttir, 2017), information overload (Anderson and Thorpe, 2004), personnel injury as a result of machine operations (Tatum and Liu, 2017), increased industry competition, and obsolescence or system failures (Strukova and Liska, 2012).

3. Research Method

This study adopted an interpretivism philosophical view using an inductive approach wherein Delphi was used to acquire qualitative data. Delphi has been described as a consensus tool that helps forecast future situations using expert opinions, especially for complex problems (Skulmoski *et al.*, 2007). Care was taken in the selection of the experts for the study. Following past submissions, the selected experts were expected to have at least 50% overall value for some defined criteria (Alomari *et al.*, 2018). They were expected to have worked extensively within the construction industry in the country, working either as an academic in a higher education institute or practicing within the industry, be part of a professional body, and have a minimum bachelor's degree (Alomari *et al.*, 2018). Based on the set criteria, out of 32 experts invited, 13 completed the two-round Delphi process. These 13 experts were considered adequate, as past studies have noted that the number of experts used in most Delphi studies ranged from 8 to 20 (Ameyaw *et al.*, 2016)

The Delphi was conducted over two rounds using a questionnaire designed with open and closed-ended questions. In the first round, the questionnaire sought answers to the background of the experts, the potential of the South African construction industry to be digitally transformed, and the time frame for this transformation to occur. The experts were also provided with some risk factors associated with construction digitalisation and were asked to rate them based on their criticality using a ten-point scale ranging from not critical to very critical. An option was given for the experts to add to the list. Lastly, the experts were asked to give the demerits of construction organisations failing to adopt the concept of digitalisation. The feedback from the first round was analysed using frequency (*f*), percentage (%), mean ($\bar{X}$), median (M), interquartile deviation (IQD), Kendall's coefficient of concordance (*W*), Chi-square (χ^2), as well as Mann-Whitney U-Test (*M-W*). Based on the analysis result, the second-round questionnaire was designed with the group M of all scores added for the experts to re-assess their responses. The experts were given the option to either agree with group M or retain their initial selection and give logical reasons. The feedback from the second round was also analysed, and the consensus was determined when 60% of all the variables achieved an IQD of 1 or less.

4. Findings and Discussion

4.1 Background information of the experts

The experts for the study were drawn from three provinces in the country vis; Gauteng (*f* = 9), Free state (*f* = 3), and Mpumalanga (*f* = 1). These experts cut across the core construction professionals such as construction manager (*f* = 6), engineers (*f* = 3), quantity surveyors (*f* = 3) and architect (*f* = 1). Regarding academic qualification, seven of the experts had a PhD, and are working in higher education institutions. The remaining six experts work in construction organisations. Four have bachelor's degrees, while two have master's degrees. Most of the experts (*f* = 11) had above ten years of working experience, with only 2 having between five to ten years. Collectively, the experts had above 50% of the set criteria and were considered fit for the study.

4.2 Digitalisation potential of the South African construction industry

Considering that the Delphi process can be used as a forecasting tool, particularly in areas with little or no knowledge (Agumba and Musonda, 2013), it became important to understand the future prospect of the South African construction industry with regard to its digital transformation. Based on this notion, the experts were first asked to rate the level of potential of the South African construction industry to be digitally transformed on a scale of one to five, with one being very low and five being very high. The result in figure 1 revealed that at the first round, most of the experts noted that the South African construction industry has a high potential to be digitally transformed, while only three experts noted that the potential is low. However, the number of those that noted a high level of potential in the industry increased to ten in the second round, while only two people insisted that the potential level was low, and one believed it was on average.

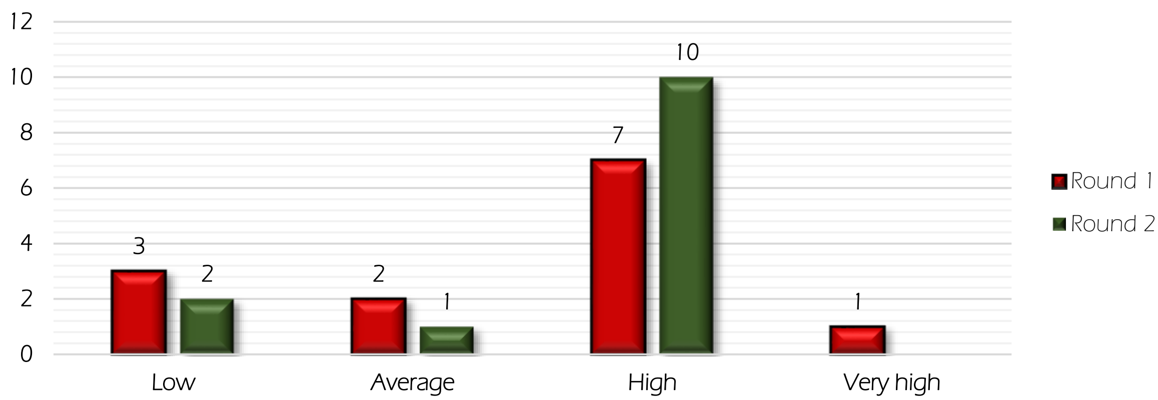

Figure 1: Digitalisation potential of the South African construction industry

Aside from understanding the potential of the South African construction industry to be digitally transformed, the envisaged timeline for this transformation to occur was also assessed. The result in figure 2 shows that at the first and second rounds, the envisaged time frame for the South African construction industry's digital transformation is between 9 to 10 years from when the study was conducted (i.e., August, 2019). Only two experts believed that this transformation was possible within a year or two from the time of conducting this study.

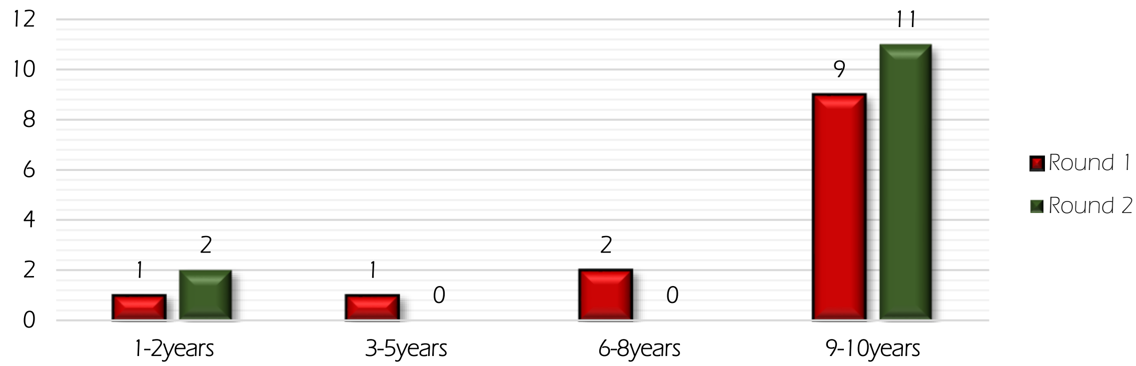

Figure 2: Timeline for the digitalisation to occur

4.3 Risks associated with the digitalisation of the South African construction industry

Delphi Round 1

The analysis of the feedback in Table 1 from the first round of the Delphi shows that only two risk factors (data insecurity and information overload) were very critical, with a group median of 10 and 9, respectively. Productivity loss was not considered a critical risk. Furthermore, the *M-W* test conducted to determine the significant difference in the rating by the experts working within higher education institutions and construction organisations revealed no disparity in how both groups of experts rated the criticality of these risk factors. This is because the *p*-value derived for all the assessed risk factors was above the 0.05 threshold. It is important to note that consensus was not achieved at the first round because the factors assessed had an IQD of above 1.

Table 1. Round 1 result of the risk associated with digitalisation

			M-W	
Risks associated with digitalisation	**M**	**IQD**	**Z**	***p*-value**
Financial investment risk	8	2.00	-1.167	0.243
Implementation and systems failure	8	2.00	-1.363	0.173
Information overload	9	3.00	-0.884	0.377
Job loss	8	2.00	-0.523	0.601
Work overload	7	2.00	-0.887	0.375
Productivity loss	4	3.00	-1.159	0.247
Overdependence on technology	7	3.00	-1.014	0.311
Data insecurity / cyber attacks	10	3.00	-2.022	0.053
Silo implementation of technologies	8	3.00	-1.774	0.076
Compliance violations with public sector practices	8	4.00	-0.872	0.383
Kendall's *W*			0.448	
χ^2			48.420	
χ^2 – Critical values from the statistical table (p = 0.05)			16.919	
Df			9	
Sig.			0.000	

Delphi Round 2

The consensus was achieved at the second round as all the risk factors assessed had an IQD of 1 and below. Furthermore, Kendall's *W* gave a value of 0.607, which is closer to one. Moreso, the computed χ^2 value of 65.542 was higher than the critical χ^2 value of 16.919 obtainable in statistical tables, thus implying a convergence in the rating of the variables by the expert. On individual assessment, the *M-W* test only revealed a disparity in the rating of one of the factors (job loss), as a *p*-value of 0.031 was derived. This implies that not all experts believe that job loss is a risk that construction organisations seeking to be digitalised should worry about. The ranking system was introduced using the group $\bar{X}$ to clearly present the most critical risk factors. From Table 2, security issues ($\bar{X}$ = 9.23) and information overload ($\bar{X}$ = 8.92) are the most critical risk factors. The least critical risk is productivity loss ($\bar{X}$ = 4.46). This implies that while construction organisations are taking measures to avoid risks such as implementation and systems failure, job loss, financial investment risk and others, emphasis must be placed on the security of sensitive organisation information and managing information. Less emphasis should be placed on productivity loss as digitalisation will help optimise the production process and not reduce it.

Table 2. Round 2 result of the risk associated with digitalisation

Risks associated with digitalisation	M	$\bar{X}$	IQD	SD	Rank	*M-W* Z	*M-W* *p*-value
Data insecurity / cyber attacks	10	9.23	0.00	2.204	1	-1.743	0.081
Information overload	9	8.92	1.00	1.115	2	-1.223	0.221
Implementation and systems failure	8	8.31	1.00	0.947	3	-1.483	0.138
Job loss	8	8.25	0.50	1.215	4	-2.162	0.031**
Financial investment risk	8	8.08	0.00	0.760	5	-1.923	0.054
Silo implementation of technologies	8	8.00	0.00	0.816	6	-0.492	0.623
Compliance violations	8	7.92	0.00	1.115	7	-1.919	0.055
Overdependence on technology	7	7.00	0.00	1.348	8	-1.030	0.303
Work overload	7	6.38	1.00	1.261	9	-0.625	0.532
Productivity loss	4	4.46	1.00	1.561	10	-0.148	0.883
Kendall's *W*						0.607	
χ^2						65.542	
χ^2 – Critical values from the statistical table (p = 0.05)						16.919	
Df						9	
Sig.						0.000	

4.4 Demerits of non-adoption of digitalisation in the South African construction industry

Delphi Round 1

In the first round of the Delphi, experts were given a blank space to fill in their views regarding the demerits of construction organisations failing to adopt the concept of digitalisation. This approach was adopted due to the lack of information in the existing literature. The feedback from the first round was analysed using content analyses by grouping like terms and themes together. At the end of the analysis, eight distinct demerits were identified and further assessed in the second round.

Delphi Round 2

The respondents were asked to rate the eight demerits identified in the first round, and the result is presented in Table 3. The *M-W* test revealed no disparity in the rating of each of these eight demerits as a *p*-value of above 0.05 was achieved. A consensus was reached for seven out of the eight assessed demerits. Kendall's *W* value of 0.298 was also derived with a computed χ^2 value of 18.746, which is higher than the critical χ^2 value of 14.067. Although Kendall's *W* value is low, and one of the assessed demerits had above 1.00 IQD, it was concluded that consensus was achieved since it was set that at least 60% of the assessed variables must have an IQD of less than or equal to 1. Table 3 revealed that the most significant demerits with the failure of construction organisations to be digitalised are lack of competitiveness in the global market ($\bar{X}$ = 9.64), increased poor-performing projects ($\bar{X}$ = 9.27), non-competitiveness of indigenous organisations ($\bar{X}$ = 9.27), and stagnation of the industry ($\bar{X}$ = 9.09).

Table 3. Demerits of non-digitalisation

Demerits of non-digitalisation	M	$\bar{X}$	IQD	SD	Rank	*M-W* Z	*M-W* *p*-value
Lack of competitiveness in the global market	10	9.64	0.00	0.809	1	-1.361	0.174
Non-competitive nature of indigenous organisations	10	9.27	0.50	1.009	3	-0.233	0.816
Increased poor-performing projects	10	9.27	1.00	1.348	2	-0.982	0.326
Stagnation of the industry /Lack of innovativeness	10	9.09	1.00	1.375	4	-0.642	0.521
Potential loss of complementary/alternative digital employment opportunities	8	8.80	1.00	1.033	5	0.000	1.000
High cost of construction in the future	8	8.73	1.00	1.348	6	0.000	1.000
Continued unsustainable reliance on manual labour	10	8.55	1.00	2.382	7	-1.535	0.125
Low labour productivity	8	7.40	1.75	2.119	8	-0.329	0.742

Kendall's *W*	0.298
χ^2	18.746
χ^2 – Critical values from the statistical table (p = 0.05)	14.067
Df	7
Sig.	0.009

4.5 Discussion

In the expert's opinion, the South African construction industry has a high potential to be digitalised. However, this transformation can take up to ten years for it to be achieved. This result can be viewed in two folds. On the one hand, the South African construction industry has the potential to be like its counterparts in other developed and developing countries that have embraced or are embracing the concept of digitalisation. This result further confirms Dall'Omo's (2017) submission that South Africa as a country has a high digital technology readiness when compared to other African countries. However, the expected time for this transformation can be far. This result can be associated with the careless attitude of the construction industry in the country to adopt technology in the delivery of their projects, as noted by Aghimien *et al.* (2019). Thus, if the timeline for this transformation is to reduce, there is a need for an awakening in terms of digital technology adoption and improvement of construction organisations' digitalisation capabilities.

The Delphi revealed that the most likely risk factors to occur are data insecurity or cyber-attacks and information overload. With organisations switching from hardware storage of data to cloud storage, they face the possibility of hacking if proper security measures are not put in place. Similarly, with the use of the internet comes the vulnerability of organisations' information being hacked by malicious individuals. Therefore, internet service providers (ISPs) and data storage organisations have crucial roles to play in ensuring the protection of organisations' information. This result is in tandem with the submission of Hudson (2017), who noted that the adoption of digital tools would ease data storage and access and increase the chances of cyber-attacks. The finding is also in line with past submissions that have shown that the fear of cyber insecurity has been the bane of the non-adoption of most technologies (Pärn and Edwards, 2019; Rubin, 2006). Spremić and Šimunic (2018) have also earlier submitted that many organisations, including large entities, do not have effective policies to address cyber risks. This might pose a big challenge for developing countries like South Africa, whose construction industry is filled with small and medium enterprises (SMEs). Therefore, construction regulatory bodies such as the Construction Industry Development Board can take the initiative to ensure that its members prioritise cybersecurity in their quest for digital transformation.

Interestingly, information overload is considered a critical risk. This can be because approaches such as data mining allow unearthing underlying issues from the enormous data being generated (Gupta and Gupta, 2010). If not adequately handled, SMEs that saturate the South African construction industry might just be overwhelmed with the amount of information they have at their disposal. Aside from these two principal risks, construction organisations might also want to look out for issues such as potential failure of the systems, job loss, financial investment risk, silo implementation of digital technologies, and the violation of compliances. These factors have come up in past studies as either a challenge or inherent issue associated with using one form of digital technology or the other (Gaille, 2016; Strukova and Liska, 2012; Zahradnik and Johnsdottir, 2017). Mzekandaba and Pazvakav (2018) discussed a PwC report that discovered that a third of jobs (especially monotonous and repetitive jobs) in South Africa are at risk of complete obsolescence with digitalisation. This has been the fear of most developing countries, with an associated risk of industrial actions among workers in protest of the use of digital technologies. It is, therefore, the duty of the different regulatory bodies in the industry to enlighten their members and the public on the notion that digitalisation is not designed to eliminate skills but rather enhance them (Holopainen and Jokikaarre, 2016).

While the aforementioned risk of construction digitalisation abounds, construction organisations might experience a lack of competitiveness in the global market if they fail to be digitalised. This is understandable as the world has become a global village. Advancement in technology is on the increase, and the construction industry in most countries will continue to evolve through the adoption of these technologies. If construction organisations in South Africa fail to evolve, they will eventually lose out on most international projects that could have benefited both these organisations and the country. Undoubtedly, the industry stands the risk of increased poor project performance, non-competitiveness of indigenous construction organisations, and stagnation of the construction industry. Abidin *et al.* (2014) noted that the construction industry continually demands organisations to improve their service for them to be competitive. To achieve this, working 'smarter' should be the watchword for construction organisations and not working 'harder'. This can be achieved through the innovative use of digital technologies (Koch and Windsperger, 2017).

5. Conclusion

This study assessed experts' views of construction digitalisation in the South African construction industry. Using a Delphi approach, the study concludes that the construction industry in the country has the potential to be digitalised; however, this might require a long time and planning to achieve. Furthermore, construction organisations need to be aware and prepared for possible risks of data insecurity, information overload, failure of digital systems, job loss, shortage in returns in investment, silo implementation and possible violations of compliances should they decide to digitalise their organisational processes. However, sticking to the traditional construction approach without digitalising will lead to a lack of competitiveness in the global market, non-competitiveness of indigenous organisations, increased poor project delivery, stagnation, loss of alternative digital employments, and high future cost construction, and continuous unsustainable reliance on manual labour.

These findings imply a need to ensure proper cyber system security by internet service providers and other related organisations to help check the cyber insecurity risk. Similarly, there is a need for the government and relevant construction bodies to support construction organisations through soft loans and other relief media to enable them to acquire the needed technologies and keep pace with the evolving digital world. Furthermore, there is a need to enlighten construction participants and the public on the role of digitalisation in promoting and improving skills rather than replacing them. Lastly, there is also the need to revisit regulations that do not favour the use of digital technologies in construction projects' delivery. The government and construction regulation bodies need to champion the quest for digitalisation by enacting favourable policies that promote technology use in construction projects within the country.

Despite the significant contribution of the study to the discourse on construction digitalisation, care must be taken in generalising its findings. First, not all participants invited to the Delphi agreed to participate. A different outcome might have been achieved had all invited experts participated. Also, the experts in the study were from three out of the nine provinces in the country. Future studies can be done in the other provinces not represented in this current study.

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The Implementations of Smart Monitoring on Construction Sites – A Literature Review

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Abstract

A critical concern with the UK's construction project progress monitoring and control techniques is their dependency on data collection, which is time-consuming and unproductive and may lead to various circumstances in managing projects. However, collecting and accurately analysing information from construction sites requires the development of technologies. As key AI technology, computer vision is a powerful tool for big data analysis which can address the above challenges. This study explores the status of computer vision-construction project management (CV-CPM) adoption and the main barriers to and incentives for its adoption within UK construction sites. In this respect, an extensive review of literature covering the AI technology in construction management, the concept, function, and usage of CV and its integration with CPM, including its benefits and drivers, and technical challenges was conducted with a specific focus on the UK construction industry. The study's results indicated that construction practitioners are relatively aware of CV-CPM but lack competencies and skills. CV-CPM has been perceived to be relatively better than the traditional approach. Implications like the cost of implementation, lack of expertise, and resistance to change were the major challenges in CV-CPM adoption. Instead, technological development, decision-making, and competitiveness were classified as incentives for its adoption. The main contribution of this study is to provide construction professionals with a comprehensive list of barriers and incentives toward CV-CPM adoption. Industry practitioners might benefit from this research's findings and detailed evaluations to develop successful adoption and transformation strategies as CV-CPM can accelerate the progress detection and data accessibility for outcomes.

Keywords

Computer vision, Project Management, Monitoring, Controlling, Artificial Intelligence, Performance, Productivity, Innovation, Automation

1. Introduction

Construction is perceived to be the largest economy in the UK; it donates almost £90b to the economy, equal to 6.7% in value-added, includes over 280,000 firms obscuring 2.93 million employments; hiring 3.1 million people or around 9% of the labour force (DBIS, 2013). However, many challenges have hindered growth and led to extremely low productivity levels compared with other industries (MGI, 2017). Many of these challenges are due to the sector remaining siloed and fragmented (CSIC, 2021) and relying on a labour-intensive business model, which has become unsustainable. Many processes have remained paper-based, information is not frequently optimised (CSIC, 2021), and eventually, reliance on manual data compilation negatively impacts site productivity and the control system, especially in controlling projects (Stilla, 2015). Some reports indicate that two-thirds of the sector fail to innovate (DBEIS, 2013). The deficiency in adopting digital technology has also been correlated to poor performance, decision-making, and cost inefficiencies and delays (Nikas *et al.*, 2007), making project management more complex and unnecessarily tedious (Delgado and Oyedele, 2021).

As highlighted previously, achieving desired performance during construction is challenging (Golparvar-Fard *et al.*, 2009). The core problems are mainly sustaining the program, ensuring the supply chain, and monitoring and controlling the work status (Teizer, 2015). The current data collection method, irrespective of project scale, indoor or outdoor, is expensive, inaccurate, and inefficient (Golparvar-fard *et al.,* 2009). Deploying a proper method with timely feedback on project status assist PMs in determining the exact percentages of task completions and facilitating resource allocation (Teizer, 2015; Alizadehsalehi and Yitmen, 2019). The recent revolution in Artificial intelligence (AI), such as computer vision, has benefited this industry in many ways, enhancing productivity (MGI, 2017). CV allows a computer to see, describe, and understand the site's extracted data (IBM, 2022). Adopting such smart technology on-site is estimated to achieve 50% to 60% construction productivity (MGI, 2017).

CV-CPM is a new concept in the construction industry. Researchers have made several efforts to review various aspects of automating CPM with different techniques. However, the literature review of related academic references demonstrated that CV-CPM adoption had received limited attention. This study investigates the key challenges in implementing CV-CPM associated with the UK construction sector and then provides recommendations to mitigate these challenges. This study explores the status of CV-CPM adoption and the main barriers to and incentives for CV-CPM adoption within UK construction sites. since the research is in progress therefore, this paper only utilize the literature review approach as discussed in Umar (2020) to arrive on current finding.

2. Literature review

2.1 Diffusion of Innovation Theory (DIT)

This study uses Rogers's (2003) diffusion of innovation theory to determine the parameters influencing incentives and barriers to CV-CPM adoption. He describes the diffusion process as gradually transmitting innovation amongst the members of a social system via special channels. The author has identified innovations' characteristics: relative advantage, compatibility, complexity, trialability, and observability. In his opinion, "innovations that individuals perceive as having a greater relative advantage, compatibility, trialability, observability and minor complexity will be adopted more rapidly than other innovations." Therefore, the perceived aspects of the invention (CV-CPM) can help identify its adoption status. Complexity assumes the relative amount of effort required to use CV-CPM. Compatibility presumes the availability of experience and resources for potential adopters to adopt CV-CPM smoothly. Trialability refers to testing CV-CPM before utilising it and observability if the impacts of using CV-CPM are straightforward.

2.2 CPM and current status

According to Acaster et al. (2017), monitoring and control are all about decision-making, and it is the centre of project management; the aim is to carry out the work according to program, resource and cost plans and maintain viability against the business case. Furthermore, monitoring collects, records, and reports information concerning project performance (PMBOKGUIDE, 2021), during the execution and pinpointing lagging areas requiring awareness and action. Inadequate and imprecise monitoring and tracking are two major factors that account for time and cost inefficiencies in projects (Ekanayake et al. 2021; Omar et al., 2018). Systematic monitoring could be complicated as the current method is time-consuming (Golparvar-Fard et al.,2009). This manual data collection causes errors and diminishes the data quality (Kiziltas and Akinci, 2005). Current methods create a bias (Mantel and Meredith, 2009). It also creates a time lag between reported and accomplished progress (Golparvar-Fard et al., 2011). It is visually complicated and does not reflect spatial features of site progress with its associated complexity (Koo and Fischer 2000).

2.3 Role of AI technology in construction management

Artificial intelligence (AI) is the backbone of this change to launch real digital strategies (Pan and Zhang, 2021). AI drives computers to sense and learns inputs like a human for perception, knowledge model, logic, problem-solving, and planning, which can deal with complicated and fuzzy problems intelligently and adaptively (Thomas and Zikopoulos, 2020: p.20). In project management makes the process more technically automatable and accurate (Pan and Zhang, 2021). The insights acquired from such cutting-edge analytics aid in better understanding the project's construction, standardising implicit knowledge from project experiences, and rapidly spotting the project matters in a data-driven manner (Hu and Castro-Lacouture, 2019).

2.4 The concept, function, and usage of (CV)

This technology stimulates computers to drive influential data from images, videos and other observable inputs and make recommendations; in effect, Artificial intelligence lets the machine judge and CV authorise them to observe and comprehend (IBM, 2022). With a large amount of visual data it generates, the construction industry can greatly benefit from the automatic extraction and analysis of this useful data (Paneru and Jeelani, 2021). A typical concept of a computer vision-based system is shown in figure 1.

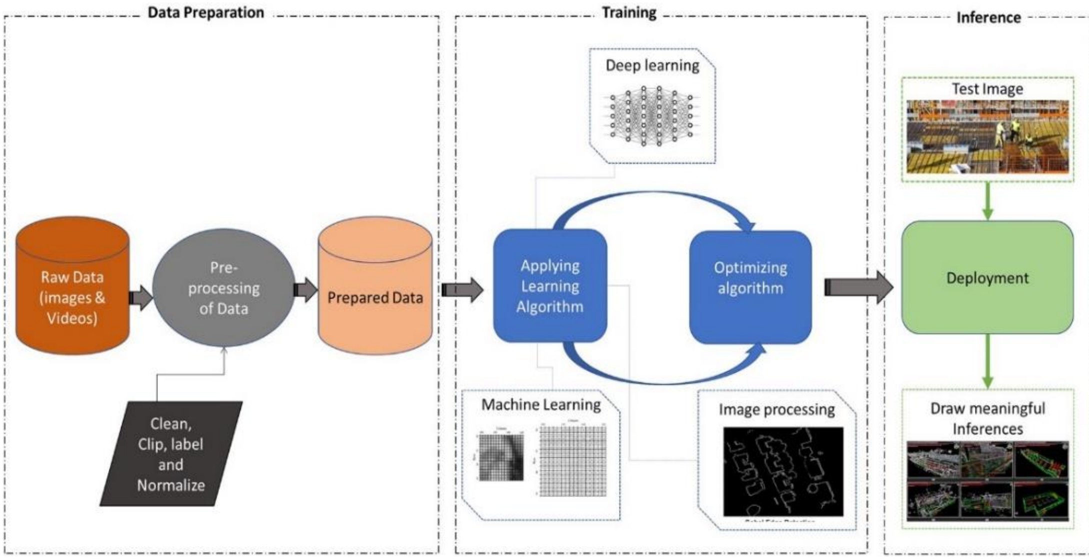

Fig. 1. A typical concept of a computer vision-based system (source: Paneru *et al.* 2021)

2.5 Integration of CV with CPM

CV has enabled the development of automating various tasks involved in progress monitoring (Paneru and Jeelani, 2021). It can trace multiple entities within a camera view and overcome current challenges (Park et al., 2011). Extracting comprehensive information from the images can help automate diverse construction-related activities (Paneru and Jeelani, 2021). CV enables computers to derive numeric information from videos, depth images and 3D point clouds, process the data, and act (Reja et al., 2022). According to Kopsida and Brilakis (2020), different technologies can generate inputs through image frames or point clouds. It can be fixed, handheld or robotic systems mounted on UGV or UAV (Adán et al., 2020). The key factors that govern their selection include the level of automation for data capture (Reja et al., 2022). Reja et al. (2022) study suggested an integrated CV-CPM framework with various concepts and technologies to automate CPM.

2.6 Benefits/Drivers

CV-CPM has the potential to create an immense impact by providing real-time, accurate, reliable information to construction managers (Reja et al., 2022). The method offers an inexpensive solution (depending on the technology) to automated monitoring processes (Panahi et al., 2022). Few scholars, including Brilakis et al. (2011); Ekanayake et al. (2021), found that using CV optimises and increases the efficiency of construction work monitoring and tracking. It also can track the activities of plants and machinery to determine their efficiencies and impact on construction progress (Morgane et al., 2022). Consistently on-demand snapshots deliver a quick assessment (Ibrahim et al., 2009) and help to optimise schedule and resource planning (Paneru and Jeelani, 2021). Prompt assessment of CV-CPM offers accuracy, reliability, and transparency (Ibrahim et al., 2009). CV-CPM authorises project hindrances to be identified earlier for respective countermeasures (Braun and Borrmann, 2019). Also, planners can check project history for delays in root cause analysis and react efficiently (Alizadehsalehi and Yitmen, 2019). CV-CPM can analyse with high effectiveness, quantify site progress, and stop PMs from manually monitoring and investigating progress status and performance, letting them focus on budget and time control (Teizer, 2015). It also helps to forecast progress and simulate and evaluates control measures to bring the project back on track (Reja et al., 2022). It will aid decrease the threat of errors and re-work and prevent time and cost deviations (Kopsida et al., 2015). Also, promoting methods to implement CV by integrating it with BIM will allow it to be further automated and reduce the extent of human intervention (Morgane et al., 2022). It would be the most appropriate input to capture geometrical attributes directly and fast (Reja et al., 2022). The visual assessment of CV-CPM can automatically detect and determine significant changes on-site by comparing digital images to the geometric and material properties of components and activities using ML algorithms (Ibrahim et al., 2009). This significantly helps PMs and project planners to control changes better.

Zhang et al. (2009) stated that CV-CPM could provide visual and quantity details, which could be utilised as evidence for potential contractual claims. (See table 1) His study has also demonstrated CV-CPM's schedule and cost control ability by constantly providing early alerts on possible delays.

Table 1. CV-CPM Added value (Source: Zhang *et al.*, 2009)

Variable	1 (very low)	2 (low)	3 (average)	4 (high)	5 (very high)	Mean	Standard Deviation
Work Package Planning and Formulation	0.0%	12.5%	12.5%	62.5%	12.5%	3.75	0.886
Cost and Schedule Control	0.0%	12.5%	12.5%	50.0%	25.0%	3.88	0.991
Calculation of Interim Valuation/Payment	0.0%	0.0%	37.5%	50.0%	12.5%	3.75	0.707
Cashflow Analysis	0.0%	0.0%	50.0%	25.5%	25.0%	3.75	0.886

CV-CPM can update schedules and generate reports/notifications, including progress quantification (Reja et al., 2022). These advantages of CV-CPM can positively influence firms to be innovative. Innovation drivers and motivation creates technological advancement (Suprun and Stewart, 2015). Several researchers claim that technological advancement is necessary if companies want to improve their competitive advantage. Competitiveness is one of the aspects impacting the maturity of the construction company for CV-CPM innovation (Johansson and Opseth, 2021). The desire of institutions to know competitive advantage is a significant driver of innovation diffusion (Sayfullina, 2010). The advantages of CV-CPM innovation include improved leadership and decision support system, save time and improve productivity, better document quality, process and performance improvement, tracking equipment and material which affects the schedule, change detection, dispute avoidance, and improve transparency and accuracy.

2.7 Challenges to CV-CPM adoption

While CV-CPM has the potential to create an enormous impact by providing real-time, accurate, reliable information to construction managers, specific challenges remain due to the construction industry's dynamic nature and site complexities (Qureshi et al., 2020). Odubiyi et al. (2019) divided the challenge to new technologies into three categories: technology, methodology, and individuals. Sardroud (2015) categorised them into cost-related, process-related, and technology-related matters, as most impediments are people-related; solutions will be discovered by scrutinising the factors that construction stakeholders perceive as hindrances. Arabshahi et al. (2021) barriers can normally be stakeholders' perceptions, such as perception of operating cost, lack of well-trained staff, and technology immaturity. The initial cost of implementation has also been cited frequently as a major obstacle (Alizadehsalehi and Yitmen, 2019). Hidden costs of training, maintenance, and operation are challenging implementation (Goodrum et al., 2011). According to Martinez et al. (2019), the cost of storing all the obtained data is a challenge. Since the construction industry is dynamic and complex, the cost of implementing new technology is a risk for most firms (Demirkesen and Tezel, 2021).

Besides cost-related barriers, challenges related to people are also involved, such as a lack of interest and well-trained staff (Singh et al., 2011; Didehvar et al., 2018). The fragmented nature of the construction sector leads to low awareness of innovative approaches and the adoption of innovative technologies (Shen et al., 2010; Evans and Heimann, 2022). The industry suffers from the low competency of construction workers and professionals (Oesterreich and Teuteberg, 2019). Recent technologies will require competencies, including skills and knowledge; competencies enable people to embrace modern technology, "adapt to its use and continue to iterate how it is used." (CITB, 2018). Hewage et al. (2008) highlighted that lack of expertise makes managers doubt whether the available labour force is confident in using modern technologies in building projects. They added that companies are reluctant to welcome recent technologies with insufficient skills and expertise. Doloi et al. (2012) believe that it becomes troublesome for construction companies to start a transformation process for industry 4.0 when expertise is lacking. According to Morgane et al. (2022), the unavailability of human resources with good proficiency in computational areas in construction would also become a barrier to implementing CV-CPM. The sector is conservative concerning embracing change; but innovative technology requires a shift, which emerges as a substantial challenge for CV-CPM adoption by the industry (Oesterreich and Teuteberg, 2016; Trstenjak and Cosic, 2017; Woodhead et al., 2018). Implementation requires process changes at all levels of the organisation; however, the industry is historically resistant to change (Young et al., 2021). Therefore, due to resistance, the construction industry has been recognised as one of the least digitised sectors (Abioye et al., 2021). Golizadeh et al. (2019) also believe that changes in the management process and complications in the construction site also influence technology adoption.

Unclear benefits and returns cause the unwillingness to welcome change and invest in innovative technologies (Demirkesen and Tezel, 2021). Several studies highlighted that companies are biased against implementing industry 4.0 and AI in construction since they are unclear about its benefits in cost savings and investment requirements; hence, they perceive modern technologies as costly to implement (Zhou et al., 2015; Oesterreich and Teuteberg, 2016; Dallasega et al., 2018). In this context, Luthra and Mangla (2018) further mentioned that most industries are reluctant to adopt smart technologies due to ignorance of the potential benefits. Therefore, it is critical for construction companies not to have a definite plan for the unknown benefits and returns on investment (ROI).

Besides, the SmartMarket report (2012) stated that 55% of companies that do not embrace automation technologies on project sites lack requirements from the client side. This means that the construction players will be more influenced by clients' demands (Kassem et al., 2012; Mitropoulos and Tatum, 2000). For example, NBS (2019) reported that the most common barriers to implementing innovative technologies are "lack of client demand" (65%) and "lack of in-house expertise" (63%). Several studies further describe the lack of clients' demand for technology adoption (Eadie et al., 2013; Vass and Gustavsson, 2017). Various Barriers identified to the adoption of CV-CPM include operation cost, cost of training and employing professionals, maintenance, cost of implementation, uncertain cost-benefit relation, operational difficulties, data management issues, and technology immaturity.

Institutional constraints may prevent the adoption of CV-CPM. The institutional theory defines the resilience and transformation of an institution. In this theory, three divers affect institutions to become isomorphic: coercive, normative, and mimetic (Cao et al., 2014). Two forces drive coercive isomorphism: pressures from other organisations on which it depends and an organisation's pressure to conform to the cultural expectations of the larger society. In a broader sense, forces bring an organisation's structure in line with the demands of powerful alters (Mizruchi and Fein, 1999). When the public sector changes requirements, the contractor is pressured to change its method. The normative refers to professional bodies developing shared norms for an organisation within a specific field. Furthermore, Mimetics stems from uncertainty. When a clear course of action is unattainable, organisational leaders may determine that the best reaction is to mimic a peer they perceive to be successful (Mizruchi and Fein, 1999).

2.8 Technical Challenges

Although CV -CPM is feasible in theory, several functional computational issues still need to be resolved (Morgane et al., 2022). Furthermore, technical difficulties such as lack of integrity, durability, and reliability negatively affect innovative technologies (Schall Jr et al., 2018; Golizadeh et al., 2019). Computer vision follows the principle of "what you see is what you can analyse" (Fang et al., 2018a; Fang et al., 2018b); hence, data collection and analysis are the two main steps in this system. Table 2 adopted based on Sami et al. (2022), represents a summary of technical limitations for each technique of CV-CPM.

Table 2. Summary of technical limitations

Techniques	challenges
UAVs (Unmanned Aerial Vehicles)	▪ It needs proper operation ▪ Requires accurate path planning ▪ Requires obstruction avoidance planning ▪ Rotational and sudden angular movements cause blur.
Handheld devices	▪ Views, angles, and coverage depends on human ▪ accessibility at the worksite Required many photographs taken manually ▪ Visual data must go through every nook and cranny of ▪ the construction feature under observation
Fixed devices	▪ Restricted to a specific view ▪ Minimal maintenance requires significant effort, i.e., ▪ crane-mounted cameras ▪ Partial coverage of construction site ▪ Demands many cameras for efficient data collection
Surveillance cameras	▪ Entails considerable memory requirements ▪ Changing weather conditions can affect the quality ▪ of data ▪ Not appropriate for minor features that require a closer view.

Structure from Motion (SfM)	▪ It takes more time to process larger vision datasets ▪ Les precise compared to other techniques.
Convolutional Neural Network (CNN)	▪ The training process requires a considerable time ▪ Higher computing power is needed than ordinary PCs ▪ It will not encode the position and orientation of construction features
Support Vector Machines (SVM)	▪ Not good for larger vision datasets ▪ Do not perform fairly when the dataset gets more noise
Simultaneous Localisation and Mapping (SLAM)	▪ Produces greater computational complexity in case larger dataset ▪ Image processing requires considerable time and memory
BIMs (Building Information Modelling) registration	▪ It does not work well with partly occluded patches in a 3D point cloud ▪ Registration of multiple point clouds causes the technical issue
Object recognition/matching	▪ No common method or technique is available to address a variety of construction. ▪ Features in terms of object recognition, matching, and tracking.

5 Discussion and Conclusion

5.1 Discussion

CV-CPM is a new technology, and the poor proficiency level is believed to be due to a lack of competencies and skills (Sami et al., 2022). Literature uncovered that the industry suffers from the low competency of construction workers and professionals (Oesterreich and Teuteberg, 2016). The review suggests that CV-CPM function is relatively better than the traditional CPM method, particularly in optimising schedules and real-time data collection capabilities. Similarly, the literature reflects that active on-demand data provide a fast and responsive assessment and assist in optimising schedules and resource planning. Change management" has also been mentioned as one of the advantages of CV-CPM as it can automatically detect and determine significant changes on-site. Automatic data collection was also ranked as the second advantage, as it can remove the extreme amount of manually data collection that causes human errors and diminish the data quality. in short, except for a few functions, the use level has shown relatively inadequate, and this reemphasises that the companies did not realise the full potential of CV-CPM in the UK (Vilde, 2021). High cost, lack of CV-CPM expertise and resistance to change are the most serious concerns for adopting CV-CPM. Because Individuals/companies perceive modern technologies transformation as a risk or consider the high cost of implementation as a serious burden since they are unclear about its benefits in terms of cost savings and investment requirements; hence, they perceive innovative technologies as costly to implement (Zhou et al., 2015; Oesterreich and Teuteberg, 2016; Dallasega et al., 2018; Demirkesen and Tezel, 2021). Lack of expertise is also listed among the important challenges for CV-CPM adoption. Given the conservative nature of the construction sector, it is unsurprising that respondents placed resistance to change as an important barrier.

In addition to the main concerns, lack of "client knowledge", "client demand", and "CV-CPM knowledge within the internal workforce" have also been noted a barriers to CV-CPM adoption. As discussed previously, lacking skills and knowledge are common issues, whether within a client or the internal workforce in construction; the absence of human resources with good proficiency in the computational field is also known as a barrier to implementing CV for CPM (Morgane et al., 2022). Client demand is also influential as construction companies will be more inspired by client demand (Kassem et al., 2012). Studies reported that unclear benefits directly affect technology adoption in the industry. The finding indicated that technological development, decision-making improvement, and competitive advantages are significant company incentives. Many authors claim that technological development is vital to boost competitive advantage. It has been theoretically justified and empirically confirmed that competition is an essential incentive for innovativeness (Mitropoulos and Tatum, 2000; Sayfullina, 2010). It motivates companies to keep their existing resilience and engage in further improvements to achieve more financial benefit.

Lastly, the role of the “partners/peers” is the most active driver to overcome the barriers of CV-CPM adoption, followed by when they realise a clear benefit and receive support from the vendor. This implies that the UK construction industry is willing to accept only when they see the result and benefits. It is believed that the influence of mimetic pressures on CV-CPM adoption can partially be mediated by client/owner/government sponsorship. As discussed in the previous paragraph, the respondent believes that companies welcome technology when they have clarity on the technological and financial benefits.

This study uncovered that respondents perceive CV-CPM as having a greater relative advantage, good compatibility with current practice, good trialability, and observability. Nevertheless, the complex process and the difficulty of learning and understanding have weakened the CV-CPM innovation diffusion process. The findings show that the "high cost and unclear benefits" are the top barriers. Moreover, looking at the institutional concept, "Our partners start using it" as a solution indicates that companies are only affected by mimetic pressure. In a broader sense, if "our partners/firms are not using CV-CPM, it can be a barrier, and when they start using it can be counted as a solution. This reveals that UK construction companies are uncertain about embracing CV-CPM due to their hesitation about the gains.

The review shows that the level of awareness of CV-CPM is fair among UK construction professionals, but they lack knowledge and skills. The method is better than the traditional approach. However, the use level is low irrespective of the company size. This may stem from the fact that the concept of a CV- CPM is still new, as evidenced by the research efforts in the form of proof of concepts, therefore, it is not surprising to be used mainly for change management and material tracking but not for progress measurement in UK construction. The review also investigated the challenges which include “cost of implementation, lack of expertise, and resistance to change” are the most serious barriers to adopting CV-CPM. It turned out that technological development, decision-making improvement, and competitive advantages are significant incentives, as technological advancement is essential to growing competitive benefits. The solutions to address the impediments of overall adoption are uncovered, which were "our partners start using it (mimicking peers) and found that the construction practitioners/companies operating in the UK are still not quite aware of the benefits and gains; therefore, they will adopt if “they see a “clear benefit" from CV-CPM implementation. It can be concluded from the study that implementation of the CV-CPM technology can accelerate the progress detection operations and data accessibility of UK construction sites. However, successful implementation has financial impacts and requires companies to have a solid strategy for unknown benefits and gains. To tackle the resistance to change issues, companies must work toward developing a changing culture or offer training to enhance the awareness of the workforce and prepare the industry for a soft transition.

The main contribution of this study is to provide construction professionals with a comprehensive list of barriers and incentives toward CV-CPM adoption. Industry practitioners might benefit from this research's findings and detailed evaluations to develop successful adoption and transformation strategies as CV-CPM can accelerate the progress detection and data accessibility for outcomes. This research is mainly based on the literature review, therefore, further data collection from construction professionals and incorporation of case studies might be more practical to monitor the practical implementation to assess better the challenges, possibilities, and drivers for CV-CPM in UK construction sites.

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