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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