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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

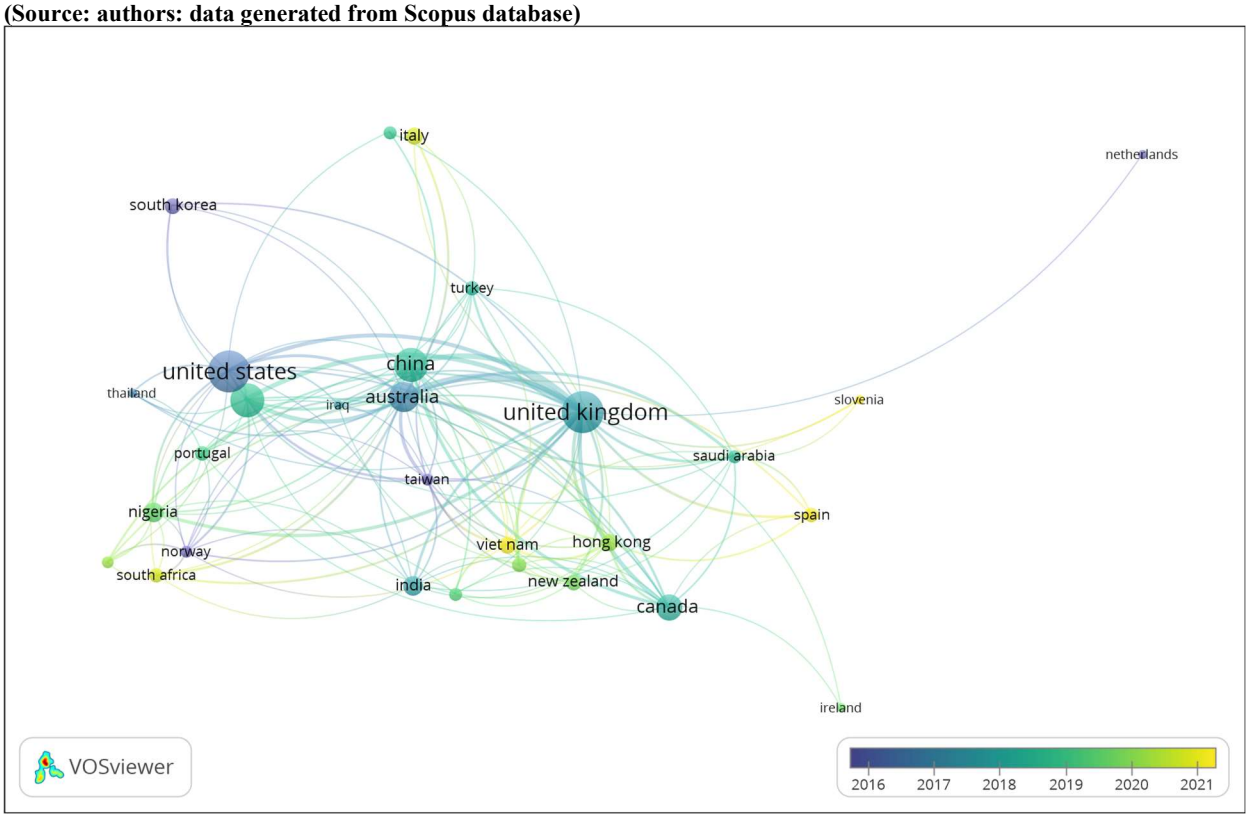
This study was conducted by reviewing existing literature on global BIM adoption and implementations in the AECOM industry using a bibliometric literature review method from the SCOPUS database. The selection of this database was as result of its broad-base and its wide recognition and utilization for 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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