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The Impact of Digital Technology on Enhancing Virtual Environment in Construction Projects

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Abstract – Advanced technological tools are crucial to generate a simulated virtual environment that allows for better collaboration, communication and data processing which ultimately leads to less errors and more successful outcomes. Available literature lacks recommendations and guidelines on which digital technologies should construction companies invest in to further enhance the virtual environment in their projects. Therefore, this paper bridges this gap by computing the relative weights of the levels of digital technologies within three categories technologies: data collection, data processing and data communication technologies in enhancing the virtual environment in construction projects. A survey was administered to construction professionals in the UAE to compare the effectiveness of digital technology levels against each other in enhancing the virtual environment of construction projects using AHP. Thirty responses were collected, and the results revealed that the most significant digital technology level with the highest impact on enhancing the virtual environment is BIM level 3. While the digital technology level that was the least significant was data collection level 1 (manual/paper-based). The results of this research are expected to provide project managers with a justified rationale for choosing to invest in advanced technological level, such as BIM level 3 and communication level 3 in order to enhance the virtualization of their construction projects.

Keywords: Digital technology, Virtual Environment, BIM, Construction Industry, Communication, Data Acquisition

1. Introduction

As populations grow and markets expand, businesses continue to look for innovative ways to survive and grow, and the construction industry is no different. In fact, the complexity and fragmentation of the construction industry makes it tough for AEC firms to stand out in all business aspects, especially in terms of productivity, time and cost efficiency, disputes resolution, and safety [1]. “Going digital” has been the trend which a lot of businesses have been trying to follow over the past few decades. Architectural, Engineering and Construction (AEC) firms have been slowly integrating digital technology in their day-to-day operations to enhance quality, efficiency, and productivity during a construction project [2]. As such, Industry 4.0 has shed light on various digital technologies such as robots, BIM, Artificial intelligence, augmented and virtual realities, cloud computing and many more, to improve automation within the sector [3]. Besides, over the past two years, the demand for digital technology has peaked due to COVID-19 pandemic, making it a necessity rather than a luxury [4].

Virtual environments using digital technologies have contributed to numerous improvements and enhancements in the AEC industry. Due to the fragmented nature of the AEC industry, continuity between the design and construction phases of a construction project has always been an issue which digital technology has successfully minimized. Standing at the forefront of digitalization, Building Information Modelling (BIM) has resolved several collaboration and clash issues, something that bridged a major gap between design and construction [5]. In addition, BIM has enabled integration of the design and construction phases with the operation phase and facility management through an improved project understanding amongst all project stakeholders as well as enhanced cost estimation and scheduling of construction projects [6]. Other issues that had their impact minimized by technologies are poor record storage and collaboration in a construction project. Cloud computing technology has allowed for remote massive storage capacities (hundreds of GBs) to minimize storing documents on site with no space and time restrictions on retrieving such data [7]. Through online clouds, big data such as models, cannot only be stored, but also viewed and shared collaboratively between project stakeholders [8]. Furthermore, the use of unmanned aerial vehicles has also been embraced in construction to conduct risk-free site inspections [9]. Other benefits offered by technology in the construction industry include ease of operation, enhanced sustainability, reduced costs, and shorter durations to deliver projects, improved communication quality, and enhanced customer satisfaction [10-12].

Although literature review has documented many benefits of digital technologies adoption in the construction industry, there is lack of guidelines or recommendations that can help construction professionals determine which levels of digital technologies they need to prioritize in order to meet the desired virtual environment degree in their construction projects. Therefore, it is important to bridge this gap and generate means for assessing the level of digital technology necessary to meet the increased demand in virtual environments. This assessment will also provide guidance for future technological investment strategies as demand increases in the AEC industry. The overarching objective of this paper is to assess the effectiveness of various digital technologies grouped within three digital technology categories to enhance the virtual environment in construction projects. The three digital technology categories are: data collection technologies, data processing technologies, and data communication technologies. In addition, this research also aims to compare the effectiveness of all the three digital technology categories against each other (e.g.: collection vs communication) in terms of achieving a higher degree of virtual environment.

2. Digital technology in the AEC industry

2.1 Data acquisition

Data collection, or acquisition, is a critical process in any construction project. It is defined as the means by which information is identified, collected, stored, transmitted, and presented [13]. In this study, data acquisition technologies will be categorized into three levels, A1, A2 and A3, in the order of increasing levels of sophistication. The categorization of these levels follows a study provided by Omar and Nehdi [14] who explained the progression in data acquisition technologies going from the conventional methods that depend heavily on manual interaction to the emergence of different automatic approaches such as multimedia and handheld computing and finally into a heavily automated data acquisition environment that consists of RFID and Laser Scanning. The levels of data acquisition technologies adopted in this research are defined below:

- A1: Manual/Paper-based – staff manually collecting data from site.
- A2: Semi-automated – CCTVs, Phone cameras, Site Tablets, Voice, multimedia.
- A3: Highly automated – 3D Laser scanning, Photogrammetry, Drones, RFID, GIS/GPS

2.2 Data processing (through Building Information Modelling)

Amongst several data processing tools in the AEC industry, Building Information Modelling (BIM) has proven itself to be a pivotal data processing tool utilized during the design and construction phases of a project. BIM is defined as a "digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition" [15]. A popular scale to measure the maturity of BIM has been developed by Zieliński and Wójtowicz [16], classifying BIM on levels ranging from 0 to 3. The scales are shown below:

- B1: BIM Level 0/1 – 2D drawing shared electronically/paper based, limited concept 3D models.
- B2: BIM Level 2 – 2D and 3D information, increased spatial coordination, models shared electronically between members.
- B3: BIM Level 3 – Collaborative, online model that includes sequencing (4D), cost information (5D), lifecycle information (6D) and more.

2.3 Data communication

In this study, data communication technologies will be categorized into three levels, C1, C2 and C3, in the order of increasing levels of sophistication. These levels are defined below:

- C1: Phone calls and Emails.
- C2: Phone calls, Emails and Video Conferencing.

- C3: Phone calls, Emails, Video Conferencing and Cloud Computing (Live Data Servers)

3. Materials and methods

The research used a mixed approach of qualitative and quantitative to differentiate between the levels of digital technology in terms of their contribution to enhancing the virtual environment of construction projects. In order to develop a spectrum of digital technology levels across each of the digital technology categories, a detailed literature review of published materials was conducted. a questionnaire survey was developed and distributed to construction professionals in the United Arab Emirates (UAE) using online means. The first part of the survey consisted of general information such as years of experience and the type of projects they work on to be able to generate a respondent's profile. In the second part of the survey, respondents were asked to conduct Analytical hierarchy process (AHP) pairwise comparisons between the effectiveness of the identified digital technology levels in the three categories of data collection, data processing and data communication in enhancing the virtual environment of the construction projects. Table 1 explains the AHP scale according to Saaty [17].

Table 1. Ratio Scales of AHP [17]

AHP Scale of Importance for Comparison of Pairs	Numeric Rating
Extremely More Important	9
Very Strongly More Important	7
Strongly More Important	5
Moderately More Important	3
Equally Important	1

In the third part of the survey respondents compared the effectiveness of the three categories of digital technologies: data acquisition, data processing and data communication in enhancing the virtual environment of construction projects. The respondent first determines which category is more significant and then determines the level of intensity of that significance according to the provided scale. The data was then analysed using Excel software to compute the local and global priorities of each digital technology category. Thirty responses were collected out of 91 distributed surveys using a snowball sampling technique, which represents a response rate of 33%. The results showed that 50% of the respondents worked in local companies while 50% worked in international companies. Additionally, 70% of the respondents worked on buildings while 30% worked on infrastructure projects.

4. Results and Discussions

The survey's comprehensive analysis is illustrated in Table 2 which shows the local and global weight of the three data technologies categories and the different levels in each category. The local weight represents the weight of each level in its corresponding digital technology category. While the global weight of each digital technology level represents the weight of each level with respect to the overall digital technologies' levels list. The results revealed that the digital technology category with the highest weight of 0.468 is data processing through BIM, followed by data communication with a weight of 0.308 and finally data collection had a weight of 0.224.

Table 2. Local and Global weights of Digital Technologies' Levels

Category	Digital Technology Levels	Category Priority	Local Weight	Global Weight
Data Collection		0.224		
	A1: Manual/Paper-based		0.065	0.0145

	A2: Semi-Automated-CCTVs, Phone cameras, Site Tablets, Voice, Multimedia		0.289	0.0647
	A3: Highly automated-3D Laser scanning, Photogrammetry, Drones, RFID, GIS/GPS		0.646	0.145
Data Processing Through BIM		0.468		
	B1: BIM Level 0/1 – 2D drawing shared electronically/paper based, limited concept 3D models		0.064	0.030
	B2: BIM Level 2 – 2D and 3D information, increased spatial coordination, models shared electronically between members.		0.343	0.161
	B3: BIM Level 3 – Collaborative, online model that includes sequencing (4D), cost information (5D), lifecycle information (6D) and more.		0.593	0.278
Data Communication		0.308		
	C1: Phone calls and Emails.		0.064	0.0197
	C2: Phone calls, Emails and Video Conferencing		0.375	0.116
	C3: Phone calls, Emails, Video Conferencing and Cloud Computing (Live Data Servers)		0.561	0.173

The results revealed that the data technology category which has the highest impact on enhancing the virtual environment of construction projects is data processing through BIM. Specifically, BIM level 3 which represents a collaborative online model that includes sequencing (4D), cost information (5D), lifecycle information (6D) and more has the highest overall global weight of 0.278. These results are in line with previous studies that emphasized the significance of data-rich BIM that simulates a virtual construction project. BIM not only demonstrates the geometry and physical properties but the whole building lifecycle with spatial relationships, fabrication, and procurement information. This ultimately leads to an enhanced virtualization of the construction project. Furthermore, the third level in communication (C3) which consists of phone calls, emails, video conferencing and cloud computing ranked second place in enhancing the virtual environment of construction projects with a global weight of 0.173. Indeed, the use of globalizing communication technology is a big catalyst for the virtualization of project teams. This advanced digital communication level simulates a real-like interaction between team members and gives project participants the flexibility to share knowledge and expertise from different time zones and locations to successfully execute the construction project [18]. On the other hand, the digital technology level that has the least impact on enhancing the virtual environment in a construction project is A1, which is the manual/paper-based data collection. In fact, this is a very traditional approach of data collection that takes a lot of time and resources and is prone to so many deficiencies and incorrect assessment of job conditions that could ultimately lead to time and cost overruns in a construction project

[44]. In light of this discussion, it is recommended that in order to enhance the virtual environment in a construction project, investment in BIM level 3 and communication level 3 should be emphasized.

5. Conclusions

Digitalization of the construction industry is a topic that has been gaining considerable attention over the past years. Advanced digital tools are essential to generate a simulated virtual environment that allows for enhanced collaboration, communication and data processing which ultimately lead to reduced errors and more successful outcomes. Available literature, however, lacks recommendations and guidance on the choice of digital technologies construction companies should invest in to further enhance virtual environment in their projects. This paper aims at bridging this gap by providing a method for computing relative weights of different levels of sophistication within the three categories of technologies: data collection, data processing and data communication technologies. A survey was administered to construction professionals in the UAE to compare the effectiveness of digital technology levels against each other in enhancing the virtual environment of construction projects using AHP. The results revealed that the most significant digital technology level with the highest impact on enhancing the virtual environment is BIM level 3 with the latest and advanced features. While the digital technology level that was the least significant was data collection level 1 (manual/paper-based). The results of this research are expected to provide project managers with a justified rationale for choosing to invest in advanced technological level, such as BIM level 3 and communication level 3 in order to enhance the virtualization of their construction projects. The main limitation of this research is the small sample size. Future research should focus on expanding the sample size to get a better understanding of the distribution of the companies. Furthermore, future research ideas include testing the hypothesis generated in this research which states that there is a positive correlation between advanced digital technology use and the overall project success using statistical tools such as structural equation modelling.

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