Drivers for Digital Twin Adoption in Construction Industry

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Digital twin (DT) is able to present digital replicas of existing assets, processes and systems. DT can integrate artificial intelligence, machine learning, and data analytics to create real-time simulation models. These models learn and update from multiple data sources to predict their physical counterparts' current and future conditions. This has promoted its relevance in various industries, including the construction industry (CI). However, recognising the existence of a distinct set of factors driving its adoption has not been established. The drivers were identified through a systematic literature review approach and integrated into a classification framework to enhance its understanding. A conceptual framework was developed to enhance the successful adoption of DT in the CI based on the identified drivers.

digital twin | drivers | construction industry

1. Introduction

The computerization and digitalization of activities and processes significantly impact how physical assets are managed [1]. Various technologies, including artificial intelligence (AI), the internet of things (IoT), building information modelling (BIM), digital twins (DTs), blockchain, machine learning, data analytics, deep learning, and the like, are being utilised to enhance productivity across several industries. Several economies are therefore confident in utilising these technologies to enhance their growth and development.

The National Aeronautics and Space Administration (NASA) presented the concept of 'twins' by building two space vehicles that were identical in nature to determine the conditions of the space vehicle while on mission [2]. Boschert and Rosen [2] further indicated that the vehicle that was on earth was the twin of the vehicle that went on a mission in space. A widely accepted introduction of DT was in 2003, where Michael Grieves presented the digital version of a physical product. In 2006, a variant of the DT known as the "product avatar" was also introduced [3]. DTs have been utilised in several industries or domains, which include the manufacturing, healthcare, aeronautics and aviation, energy, education, agriculture, meteorology, and automotive sectors [4]. Although DT adoption in the construction industry has been quite slow [5], most of its application has been focused on the operation and maintenance phase of projects.

Notwithstanding the efforts and quest for DT in the construction industry, little attention has been geared towards the driving forces for its adoption. The drivers will serve as a blueprint for practitioners and stakeholders to better understand DT and its potential success in the construction industry.

2. Classification of the DT in Construction Industry Drivers

The lifecycle philosophy of construction projects is critical to the successful adoption of DT due to the integrated activities on design, construction, operation and maintenance, and preservation [5]. The construction project lifecycle phases as described by Guo, Li and Skitmore [6] is adopted here. The planning and design phases are referred to as design; construction and commissioning phases are referred to as construction; utilization and maintenance phases are referred to as facilities management; finally, decommissioning phase is referred to as restoration and refurbishment.

Either similar or dissimilar variables are consolidated into broader higher-order categories. The purpose of the consolidation was to enhance the understanding, clarity and simplicity of the identified drivers. The classification technique utilised by Ghobadi [7] and Chan, Tetteh and Nani are adopted [8]. This technique defines the categories based on four robust codified logic. For instance, Ghobadi [7] adopted this approach to develop a framework for classifying the driving forces for knowledge sharing in software teams using the change perspective of organisations. Chan, Tetteh and Nani [8] also utilised the same approach to develop a conceptual framework to guide, determine and assess the success of international construction joint ventures. The codified logic involves, firstly, identifying the interrelationships between the identified factors. Secondly, comparing the results to ensure consistency within the categorisation of the factors. Thirdly, establishing a relationship between classifications of previous studies and the current results and, lastly, finalising the categorisation of the factors using focus group discussions.

The classification process resulted in the 50 drivers being classified into four major categories. These categories include concept-oriented drivers, production-driven factors, operational success, and preservation-driven drivers (see **Table 1**). Furthermore, these categories have also been ranked to establish the most frequent usage of DT in the construction industry.

Table 1. Typology of Drivers for DT adoption in construction industry (CI) ranking.

No.	Categories	Drivers	Code	Frequency	Mean	Rank
1.0	Concept-oriented drivers		COD		4.00	1st
1.1		Real-time data visualisation	cod1	18	-	
1.2		Reduce overall design process	cod2	5	-	
1.3		Enhanced decision-making	cod3	5	-	
1.4		Sustainability in project design	cod4	5	-	
1.5		Encourage digital transformation	cod5	4	-	
1.6		Improved design information delivery	cod6	4	-	

No.	Categories	Drivers	Code	Frequency	Mean	Rank
1.7		Improved materials selection	cod7	3	-	
1.8		Enabled smart services	cod8	3	-	
1.9		Ensure effective project planning	cod9	2	-	
1.10		Provide technical solutions	cod10	2	-	
1.11		Finite elemental analysis of existing structures	cod11	2	-	
1.12		Creation of asset value	cod12	1	-	
1.13		Social support	cod13	1	-	
1.14		Capacity of improving building data	cod14	1	-	
2.0	Operational success drivers		OSD		3.13	2nd
2.1		Enhanced environmental monitoring	osd1	8	-	
2.2		Enhanced energy management	osd2	7	-	
2.3		Continuous monitoring of assets	osd3	6	-	
2.4		Enhanced predictive maintenance	osd4	5	-	
2.5		Real-world asset management	osd5	4	-	
2.6		Improved project’s operation efficiency	osd6	3	-	
2.7		Automation and real-time control	osd7	3	-	
2.8		Better project operational performance	osd8	3	-	
2.9		Real-time networking of products and systems	osd9	2	-	
2.10		Maintain occupants’ comfort	osd10	2	-	
2.11		Develop self-learning capabilities	osd11	2	-	
2.12		Enhanced operational cost	osd12	1	-	
2.13		Improved self-management ergonomic exposure	osd13	1	-	
2.14		Secure systems	osd14	1	-	

No.	Categories	Drivers	Code	Frequency	Mean	Rank
2.15		Feedback to improve personal satisfaction	osd15	1	-	
2.16		Improved climate conditions	osd16	1	-	
3.0	Production-driven drivers		PDD		2.73	3rd
3.1		Optimise construction process	pdd1	10	-	
3.2		Safety risk management	pdd2	7	-	
3.3		Reduced construction cost	pdd3	5	-	
3.4		Enhance logistics monitoring and simulations	pdd4	3	-	
3.5		Understand structural actions	pdd5	2	-	
3.6		Reduced logistics risk	pdd6	2	-	
3.7		Improved product quality	pdd7	2	-	
3.8		Effective stakeholder collaboration	pdd8	2	-	
3.9		Deliver new products or services	pdd9	1	-	
3.10		Better project management	pdd10	2	-	
3.11		Output controlling of complex systems	pdd11	1	-	
3.12		Enhanced prefabrication of assets	pdd12	1	-	
3.13		Reduced non-fatal injuries	pdd13	1	-	
3.14		Improved management activities	pdd14	1	-	
3.15		Effective stakeholder management	pdd15	1	-	
4.0	Preservation-driven drivers		PRD		1.20	4th
4.1		Conserve heritage assets	prd1	2	-	
4.2		Proactive and accurate status information	prd2	1	-	
4.3		Preserve cultural heritage	Prd3	1	-	
4.4		Enhanced building retrofit	Prd4	1	-	

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2. Boschert, S.; Rosen, R. Digital Twin—The Simulation Aspect; Springer International Publishing: Cham, Switzerland, 2016; pp. 59–74.

No.	Categories	Drivers	Code	Frequency	Mean Rank
4.5		Improved renovation works	Prd5	1	-

Table 1 shows the identified four main categories and their associated driving forces for DT adoption in the construction industry. For instance, conserve heritage assets, proactive and accurate status information, preserve cultural heritage, enhanced building retrofit, and improved renovation work form the preservation-driven drivers for adopting DT in the construction industry.

2.1. Concept-Oriented Drivers

The concept-oriented drivers are drivers that form the baseline for DT adoption in the construction industry. These drivers are generally realised at the concept or design and engineering stage of the project. They set the pace for adopting DT in the construction industry. Within this construct, 14 drivers were identified to include real-time data visualisation, reduce overall design process, enhanced decision-making, sustainability in project design, encourage digital transformation, improved design information delivery, improved materials selection, enabled smart services, ensure effective project planning, provide technical solutions, finite elemental analysis of existing structures, creation of asset value, social support, and capacity of improving building data. This is the initial decision-making stage; the decision on whether to adopt DT is very critical [9]. The behaviour role of the physical entity is reflected in a DT and would be kept updated throughout the lifecycle of the construction project. The concept-oriented drivers are therefore essential in ensuring that the most critical decisions are made regarding the project. Designers are, therefore, provided with efficient information during the design of the project. Hence, a complete digital project footprint will be available to designers to aid them in making informed decisions once they have a DT [10].

Regarding the design process for a building project, DT can aid in reducing the overall design process. This is possible since at the designing of a project, DT can inform the designers' decision as to which hereditary components, as well as information, can be used from a previous project or rejected during the redesign and re-engineering of the project. Lydon, Caranovic, Hischier and Schlueter [11] stated that DT could reduce the high planning resources needed to implement the elements of multifunctional buildings. The authors further mentioned that the application of DT could resolve issues related to building systems performance during the design and support the various methods employed in digital fabrication during the construction of the project. DT plays a significant role in minimising the duration of the overall design process. For instance, Opoku, Perera, Osei-Kyei and Rashidi [5] mentioned that DT ensures an iterative optimisation of the information and product physical models and, therefore, reduces the overall design process. This can help in reducing the possibilities of incurring additional costs during rework.

2.2. Production-Driven Drivers

The production-driven drivers focus on bringing the construction project into being. This is the stage where the industry receives its finished product. The production-driven driving forces ensure that the integrity of the project's structural system is achieved [12]. Considering the definition and theoretical background of the production-driven

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drivers, 15 drivers were classified under this category to include optimise construction process, safety risk management, reduced construction cost, enhanced logistics monitoring and simulations, understand structural actions, reduced logistics risk, improved product quality, effective stakeholder collaboration, deliver new products or services, better project management, output controlling of complex systems, enhanced prefabrication of assets, reduced non-fatal injuries, improved management activities, and effective stakeholder management. The strength of PD drivers lies in its ability to bring into being the building project [5][11][13][14].

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2.3. Operational Success Drivers

The operational success drivers establish the relationship between the construction project and its users. This is the point where the project's reliability, as well as its convenience, are of utmost importance to its users. Several stakeholders operate the construction project and, therefore, prevent the data integration between different stakeholders and the project. The adoption of DT at a project's operation and maintenance stage is usually centred on facilities and maintenance management [5][15][16]. The flow of information among the different stakeholders could also be improved through the application of DT. The operational success drivers category is the second highest ranked category, with a mean value of 3.13, and is explained by sixteen different drivers. The OSD category includes enhanced environmental monitoring, enhanced energy management, continuous monitoring of assets, enhanced predictive maintenance, real-world asset management, improved projects' operation efficiency, automation and real-time control, better project operational performance, real-time networking of products and systems, maintain occupants' comfort, develop self-learning capabilities, enhanced operational cost, improved self-management ergonomic exposure, secure systems, feedback to improve personal satisfaction, and improved climate conditions. It is worth to noting that this category has been identified as one of the most significant determinants for adopting DTs in the construction industry, as reported by Opoku, Perera, Osei-Kyei and Rashidi [5].

2.4. Preservation-Driven Drivers

Different from the regular use of DT in the construction industry, the preservation-driven drivers focus on preserving or conserving the construction asset for future use. Per the definition of the PR drivers and its theoretical background, five out of the fifty drivers were classified under this category, which include conserve heritage assets, proactive and accurate status information, preserve cultural heritage, enhanced building retrofit, and improved renovation works. As Opoku et al. (2021) indicated, researchers have geared little attention towards the demolition and recovery phase of projects regarding the adoption of DT in the construction industry. However, an important area of DT application is that of the preservation of heritage assets, which may possibly be demolished later. The PRD construct is the least ranked among the four categories based the frequency of citations, with a mean value of 1.20.

Notwithstanding, the drivers underlying this category are important for the sustainability together with the continuous evolution of the construction industry [12][17].

3. Conclusions

The descriptive analysis indicates a growing interest in DT adoption in the construction industry among researchers with studies from both developed as well as developing countries. The findings indicate that majority of the developed countries, which includes the UK, US, Australia and Italy, have the highest number of researchers contributing to the probing of the driving forces for the adoption of DT in the construction industry. In the same vein, developing countries like Brazil, China, and South Africa have also contributed to the DT adoption in the construction industry. The comprehensive content analysis resulted in the identification of 50 drivers for the adoption of DT in the construction industry. The 50 driving forces were extracted, classified and integrated in a framework. The classification framework includes four key categories, specifically: concept-oriented drivers, operational success drivers, production-driven drivers, and preservation-driven drivers.