Challenges of Digital Twin Technologies Integration in Modular Construction: A Case from a Manufacturer's Perspective

Laith Jamal Aldabbas
Al-Ahliyya Amman University, Amman, Jordan

***Abstract*—Automated models of physical objects are known as Digital twins; letting one to outline, test, array, and monitor and manage robotics in the real world. .CPS (Cyber-physical system) data have to be assembled through real life procedures to form a real-time monitoring cyber model in order to produce Digital Twin. Modification in the cyber model will be shown in real life system to guess or manage. As a result of digital and the progression in ICT, manufacturing and aviation or aerospace industries are now utilizing digital twin. Nonetheless, the uses of DT's in several production firms have not been researched massively. Those studies were sparse in construction, where structures are built without Superstructures, which thus sparked global concern. Herein, DT applications in building/manufacturing sector and in various firms were reviewed first and thereafter aimed on publications concerning DT applications in industry area by organizing a systematic search via Scopus. Notably, the publications were singled out immediately after the assessment of the publications and the study continues to investigate and evaluate the Potentials of digital twins in MIC, Restriction of digital twins in MIC, Impact of digital twins on industry, and Cost of time which should be appropriate for model development. The analysis report however demonstrated that DT is dedicated and thoughtful of in midst of inclusion along other digital technologies. More so, theoretical structure is formed in order to apply DT in module installation in MiC around the circumstances of Hong Kong which happens to be usual city case of high-density. Interestingly, the implementation of Digital twin in Modular Integrated Construction is expected to provide promising potential with significant benefits, such as improved logistics and manufacturing management by employing Digital Twins to track on-site progress during module installation.**

***Keyword*—Digital Twin; DTs; enabling technologies; digital twin model; applications; challenges; literature review**

I. Introduction

Digital twin is subjected to intensive scrutiny. Both the Digital Model and the Digital Shadow identifies an infrastructure relationship between digital and physical components that is either unequal or unidentified [1]. A self-contained digital data structure that is related to a physical system is referred to as a DT. This information would be a "twin" of the raw document that was stored electronically in the physical system and was related to throughout its existence. According to the findings of [2] the term "Digital Twin" has been utilised to signify a variety of different numerical and physical links. Integration can be improved with the help of a DT by evaluating and reviewing the status of both physical and digital elements simultaneously.

This article examines the most recent developments in digital technology, information technology, and digital twins, as well as the influence such developments have had on the industry. Secondly, it places an emphasis on the integration of Digital Twin technologies with BIM; which is the most recent digital technology that is supported whilst WSN and internet of things was talked about as well. Third, the article discusses the benefits of utilising Digital Twin technology as well as the challenges that must be overcome prior to its widespread adoption in the industrial industry. Implementation of DT in manufacturing area and in various firms was reviewed and aimed on publications concerning DT Implementation in industry area by performing a systematic search via Scopus. As soon as the reviewing publication procedure and evaluation were filtered out, the paper propels in examining and evaluating the potentials of digital twins in MIC, Restriction of digital twins in MIC, Impact of digital twins on industry, and Cost of time which should be appropriate for model development. The findings however unveiled DT to be esteemed with other digital technologies for inclusion**.**

A. Hong Kong Scenario

Manufacturing is the intended application for the suggested digital twin technology architecture in MIC modules [3]. The implementation of digital twin technologies in manufacturing presents a number of opportunities and advantages [4]. Economic growth and social advancement has been sustained by the construction industries in Hong Kong. It has added about 4.5% of Gross Domestic Product (GDP), 2018 [5]. Yet the industries continue to experience hard challenges, for instance, aging workforce, labour shortage and cost inflation [6]. Thus, it was announced within 2017 and 2018 by Policy Address of Government of Hong Kong Special Administrative Region (HKSAR) for government to welcome and propagate MiC in civil works firms [7,8].

In contrast to normal construction methods, MiC has distinguished its abilities whereby a huge of on-site works is relocated to an industry to produce modules. Building services, architectural works and structural works of modules were partly achieved, thereafter, accompanied by module transportation to construction site for coupling and installation. Thus, many MiC utilized projects has begun so as to propel its notable acceptance in Hong Kong.

B. Research Gaps and Future Motivation

This study is built through the previous literature on digital twins and modular integrated construction. It is important to start the study by examining the literature and finding out the research gaps. On the bases of the literature, the following research gaps have to be addressed.

1) Potential of digital twins in MIC.
2) Restriction of digital twins in MIC.
3) Impact of digital twins on industry.
4) Cost of time should be appropriate for model development.

C. Literature Review

Notably, the term "digital twin" (DT) was first defined by NASA in their Technology Roadmap in the year 2010; referred to as an integrated multi-physics, multi-scale, probabilistic simulation of in-built vehicle or framework which utilizes a better suitable real life models, sensor updates, fleet history, etc., to reflect the life of its proportional flying twin [9]. Around 2015, the idea of DT was attuned as composing a generic 'product,' other industries, including manufacturing, industrial engineering, and informatics, began to employ it as part of their business operations. DT thus stands for "design thinking" [10].

Consequently, DT applies to all phases that has to do with product existence and not solely to give out a depiction of the actual product [11][12]. The following is an example of a general definition of DT provided by [13] in the year 2012, and widely acknowledged and utilised Digital twin refers to "an integrated multi-physics, multi-scale, probabilistic simulation of a complex product". This simulation uses the most recent and accurate physical models, sensor readings, and other data to "mirror" the life of the product's "matching twin." A real-time reflection is one of the characteristics that help to define DT, and its definition also sheds light on this characteristic [14]. DT makes it possible for information about the real space to be studied in the physical world in a manner that is accurate and up to date while maintaining a high level of synchronisation and precision. The capability of DT to evolve on its own is also an essential feature of the methodology. In contrast to the actual and virtual worlds, the model used in the virtual environment is susceptible to continuous alterations made in real-time [15].

II. RESEARCH METHODOLOGY

This paper adopts a systematic literature review to highlight opportunities and restrictions in implementing digital twin technology in building projects. The research necessary material used in investigation was gotten via academic search engine database such as Google scholar, science direct, and academia. The analysis focused on the most recent 12 years' worth of publishing, extending from 2010 to 2022. The database allows users to modify the settings for how searches are performed. The search approach had electronic databases of Scopus. The search phrases "digital twin in construction," "semantic web," or "MIC" were used to rectify the breakthroughs in the scope of research. The initial search suggested that 6890 papers were published on digital twin applications, out of which 4490 were published since 2019. Although much research has been published on digital twins, the authors further confined the search to journal and conference articles only in the "civil engineering domain" via Google scholar, science direct, and academia. More so, with deep investigation of the paper's abstract from the improved search, about 58 manuscripts for the systematic review analysis were realized. Reports were utilized as references from government and non-government organisations to assist the triangulation of the literature that was done in this study.

III. RESEARCH PROGRESSED

A. Examining Current Procedures

The most recent search of manuscripts through Scopus' digital libraries took place in May 2022. In the initial investigation, all papers were subjected to the selection criteria outlined in Section III. A total of 54 publications were called for further examination, after checking the headlines, titles, synopsis, and primary contents of filtered publications, a total of 19 articles were found. All of the publications found in line with DT usage in the civil works industry [16]. The first essay on the subject was published in 2018 the Journal articles and conference papers were evenly distributed among the selected publications. Fig. 1 depicts the disruption in publication timing and format of the recognized publications.

Three of the papers found looked at the use of DT not just during the building phase, however throughout the cycle of the project from inception to operation and maintenance. One of the goals of the DT application is to automate job planning and scheduling. Real-time data collection from a construction site allows for monitoring and appraisal of construction performance [17]. One study generated DT of a type of machinery to reduce production time and cost while other study formed DT as a type of construction tool for simulation to lessen manufacturing time and cost. Fig. 2 shows an outline of the various aims of DT applications spotted in publications.

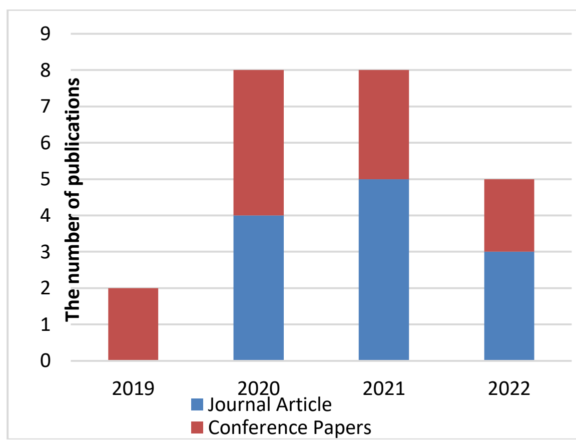

Fig. 1. Time of publishing and types of articles detected as of May 2022.

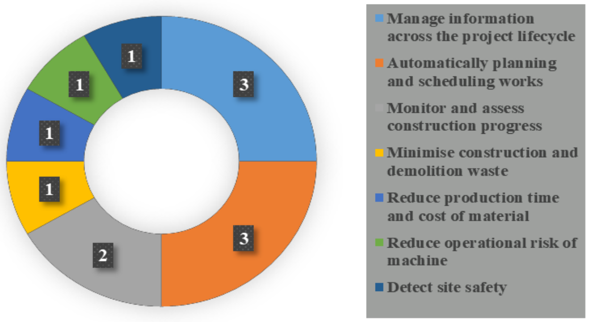

Fig. 2. An outline of the prospects for DT application within researched articles.

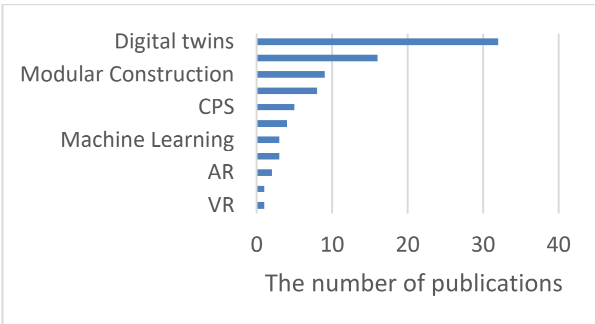

Fig. 3. Frequency with which DTs are published.

The number of articles with the keyword digital twins is 32 while, integrated modular construction related are nine articles. 15 studies cited "Building Information Modelling (BIM)," with 10 employing DT as an evolutionary representation and five considering the BIM system as DT. Only one article discusses "Wireless Sensor Network" (WSN) in connection with IoT for real-time data transfer. Three publications mentioned "cloud platform" for storing, analysing, processing, and combining data. Three publications reference "machine learning" for self-learning DT. Augmented and Virtual Reality can benefit from Digital Twins since they give immersive aim for viewing historical and real-time data [18]. Fig. 3 illustrates how often Digital twins, Modular construction, blockchain, BIM, IoT/sensor, WSN, cloud platform, machine learning, AR, and VR were referenced.

IV. Findings

A comprehensive study was conducted to identify and synthesize the primary procedures for collecting, transmitting, modeling, integrating data, service for digital twin technologies (Table I) (Fig. 4). Section 4A discusses the pros and difficulties associated with digital twins.

A. Assessing Digital Twin Applications

1) Potential of the applications: Digital twins aid in disaster preparation and asset management. Digital twin models help stakeholders comprehend obstacles and constraints, such as predicting the status of a physical asset, forecasting energy usage while preserving environmental norms, and monitoring structural infrastructure health. AI algorithms and data analytics help digital twin models forecast or back cast. The future status of an asset may be compared to the intended state. Digital twins help stakeholders choose low-carbon, clean-energy designs. Iterative design methods can promote generative design while addressing cost, schedule, and environmental benefits. Real-time data updates monitor construction workers for body segment hazards. Real-time reports on installation activity are needed in dangerous regions like nuclear power plants to protect personnel and limit human intervention. Digital twin models use data like population preferences and material usage priorities for urban planning and design. Using citizen or end-user data, digital twin models could connect people to buildings/cities.

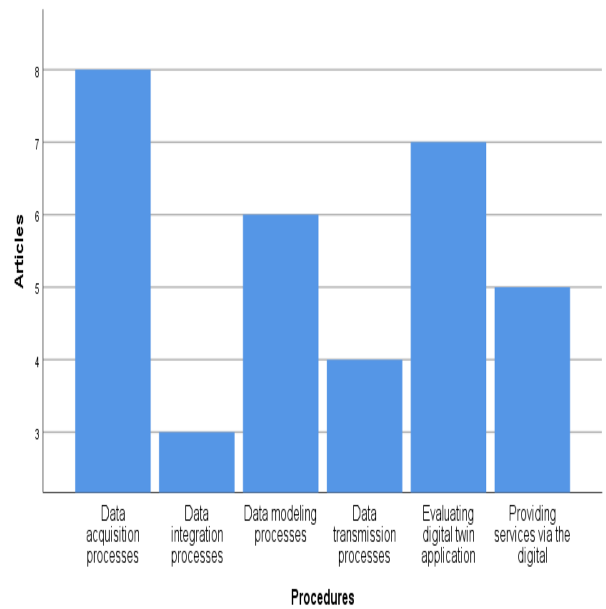

Fig. 4. Bar chart for the findings.

TABLE I. Digital Technology usage and Establishment

Data acquisition	Data transmission	Digital modeling	Data/model integration	Service/objective	Reference
Sensors, RFID	Internet	Geometric model (3D)	Virtual platform	Simulation model	[19]
GIS, BIM data	Internet	CIMs, BIMs	Cloud computing	Controlling and monitoring physical site	[20]
Real-time sensor	Internet	BIMs	Data analysis	Detection of maintenance and operation	[21]
Geospatial dataset	Internet	BIMs	Big data	Simulation for urban	[22]
IOT sensor	Internet	Thermography map	Machine learning algorithm	Renovations for energy planning	[23]

2) Restriction of digital twins in MIC: Herein, some of DT challenges cannot be overlooked. According to the literature, data integration is vital to link digital twin to physical assets. Surprisingly, integrating data from different technologies is difficult. DT data is housed in various systems which make it hard to compare with machines, for instance the heterogeneous data source. Data base terminology varies by system and maintaining feedback loops requires data synchronising. Extraction or modification of data reduces quality. DT requires real-time data transfer, which is expensive and time consuming. Digital twin models are subject to digital threats; therefore, data security and privacy is crucial [24]. Digital twins need uniform data transmission and sharing standards. Sensor installation and maintenance rarely concern construction personnel. Construction sensors can be stolen. These devices must save, filter, and match data with BIM models. Construction assets need lifecycle maintenance to survive decades. Construction is complicated and involves many stakeholders. Thus all project members must work together. Multiple stakeholders may impede asset and digital twin model building. Digital twins require experienced builders, money, and high-powered technologies.

3) Impact of digital twins on industry: A digital twin assists the production companies to grow its productivity, pliability and capability. They also improve on efficiencies without undermining the involvement of human by utilizing data-driven decision-making. Production system upgraded by digital simulation can be both cost and time-effective. Most institutions reproduce as well as examine every detail of production before it starts [25]. Manufacturers have the tendency to investigate unalike materials, colours and textures preliminary to production along visualization tools. Using a digital twin gives a better blueprint and tool of implementation to construct synthetic scenarios that are useful as tools for training and management continuation. These provide one with clarity to operate machines, systems and processes. Technically, it functions as a communication tool as it enhances the identification of variables one would like to observe. More so, digital twin can foretell about the state of the future of its real life counterpart. It has the ability to bring about what-if scenarios that are dangerous or cost-prohibitive in reality. This system can be perturbed to create unexpected scenarios and examine the system's response and the appropriate mitigation techniques. A digital twin is the only way to do this examination without putting the real asset at risk. Transparency can be improved by making real-time information available and automating the reporting process [26].

4) Cost of time should be appropriate for model development: To ensure the viability and acceptance of technology developments in building, the underlying causes must be effectively addressed. Low productivity, bad industrial image, low predictability, structural fragmentation, and lack of Research and development (R&D) and investment in innovation are some of the industry's issues affecting the construction sector; however investment in DT can help alleviate some of them [27]. Digital twins require experienced builders, money, and high-powered technologies.

Once the DT requirement is acknowledged, the initial building pace of the digital twin is generally achieved already, as these demands serve as the basis for determining which programs should be utilized, what platforms are necessary, how much it would cost, and how difficult the digital twin will be. Time and money can be saved, as no processes have to occur physically for the identification to take place; it is known ahead of time what works and what doesn't. Money can be realized first via time; time is not returnable or stored, and by optimizing the relevant model, money is automatically saved. Obviously, several producing companies have only defined capacity of machine, and every job needs to be scheduled within the scope of the machine. Interestingly, through the use of digital twin, companies like mentioned above can pre-schedule their jobs to perfect the use of money and thus optimise the availability of time to be proportional with the mode; growth as much as possible. Notably, as time turn out to be sole driver, costs are diminished as hourly rates stand the same [28].

V. Conclusion

This paper gives the outline of academic publications connected to DT applications within industries, specifically in the building / manufacturing industry. The purpose of this paper is to evaluate the potential and restrictions of Digital twin integration for MiC. Through literature review, a total of 19 articles were found. All of the publications found are connected to the use of DT in the building construction industry. The primary goal of DT is to enable the manufacturing process to be optimized by incorporating seized time-sensitive information for efficient tracking. Additionally, it aims to incorporate flexibility and customization in all production methodologies and variables while maintaining complete authority. In cause of the literature gap findings, we were able to lay emphasis on Potential of digital twins in MIC, Restriction of digital twins in MIC, Impact of digital twins on industry, and Cost of time which should be appropriate for model development.

However, in the future, the applications for digital twins should be thoughtful of upcoming literature review and meta-analysis of publications on DT applications in the manufacturing area through more electronic databases; have collaboration in middle of the stakeholders to guarantee that the appropriate amount of time is spent on model development. Construction industry should primarily emphasize on the education and growth of qualified personnel, particularly for digital twin applications. During the decision-making process, the linked parties should also consider the matter of budget planning as well as to centre on group discussion or meetings with academics and practitioners in the areas of DT and modular building.

ACKNOWLEDGMENT

I am very grateful to my faculty unit for their encouragement.

CONSENT FOR PUBLICATION

The authors grant International Journal of Advanced Computer Science and Applications the consent to publish the manuscript.

DISCLOSURE

The author declares no conflict of interest.

FUNDING STATEMENT

This research has not been funded by any source.

REFERENCES

[1] Lee, J., Kao, H. A., & Yang, S. (2014). Service innovation and smart analytics for industry 4.0 and big data environment. Procediacirp, 16, 3-8.

[2] Douthwaite, J. A., Lesage, B., Gleirscher, M., Calinescu, R., Aitken, J. M., Alexander, R., & Law, J. (2021). A modular digital twinning framework for safety assurance of collaborative robotics. Frontiers in Robotics and AI, 8.

[3] Bertram, N., Fuchs, S., Mischke, J., Palter, R., Strube, G., &Woetzel, J. (2019). Modular construction: From projects to products. McKinsey & Company: Capital Projects & Infrastructure, 1-34.

[4] Biesinger, F., Meike, D., Kraß, B., &Weyrich, M. (2018, September). A case study for a digital twin of body-in-white production systems general concept for automated updating of planning projects in the digital factory. In 2018 IEEE 23rd international conference on emerging technologies and factory automation (ETFA) (Vol. 1, pp. 19-26). IEEE.

[5] Lu Q., Xie X., Parlikad A.K. and Schooling J.M.Digital twin-enabled anomaly detection for builtassetmonitoringinoperationandmaintenance.Automation in Construction, 118(2020): 103277,2020.

[6] Census and Statistics Department. GDP by majoreconomic activity.Online:https://www.censtatd.gov.hk/hkstat/sub/sp250.jsp?tableID=036&ID=0&productType=8#N3, Access:06/05/2020.

[7] ChiefExecutive.TheChiefExecutive's2017Policy Address: Make Best Use of OpportunitiesDevelop the Economy, Improve People Livelihood,BuildanInclusiveSociety.Online:https://www.policyaddress.gov.hk/jan2017/eng/pdf/PA2017.pdf,Access:06/05/2020.

[8] ChiefExecutive.TheChiefExecutive's2018Policy Address: Striving Ahead Rekindling Hope.Online:https://www.policyaddress.gov.hk/2018/eng/pdf/PA2018.pdf,Access:06/05/2020.

[9] Shafto, M., Conroy, M., Doyle, R., Glaessgen, E., Kemp, C., Le Moigne, J., & Wang, L. (2012). Modeling, simulation, information technology & processing roadmap. National Aeronautics and Space Administration, 32(2012), 1-38.

[10] Negri, E., Fumagalli, L., &Macchi, M. (2017). A review of the roles of digital twin in CPS-based production systems. Procedia manufacturing, 11, 939-948.

[11] Glaessgen, E., &Stargel, D. (2012). The digital twin paradigm for future NASA and US Air Force vehicles. In 53rd AIAA/ASME/ASCE/AHS/ASC structures, structural dynamics and materials conference 20th AIAA/ASME/AHS adaptive structures conference 14th AIAA (p. 1818).

[12] Kraft, E. M. (2016). The air force digital thread/digital twin-life cycle integration and use of computational and experimental knowledge. In 54th AIAA aerospace sciences meeting (p. 0897).

[13] Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. The International Journal of Advanced Manufacturing Technology, 94(9), 3563-3576.

[14] Tuegel, E. J., Ingraffea, A. R., Eason, T. G., &Spottswood, S. M. (2011). Reengineering aircraft structural life prediction using a digital twin. International Journal of Aerospace Engineering, 2011.

[15] Jiang, Y., Li, M., Guo, D., Wu, W., Zhong, R. Y., & Huang, G. Q. (2022). Digital twin-enabled smart modular integrated construction system for on-site assembly. Computers in Industry, 136, 103594.

[16] Jones, D., Snider, C., Nassehi, A., Yon, J., & Hicks, B. (2020). Characterising the Digital Twin: A systematic literature review. CIRP Journal of Manufacturing Science and Technology, 29, 36-52.

[17] Lee, D., & Lee, S. (2021). Digital twin for supply chain coordination in modular construction. Applied Sciences, 11(13), 5909.

[18] Lee, D., Lee, S. H., Masoud, N., Krishnan, M. S., & Li, V. C. (2021). Integrated digital twin and blockchain framework to support accountable information sharing in construction projects. Automation in construction, 127, 103688.

[19] Lim, K. Y. H., Zheng, P., & Chen, C. H. (2020). A state-of-the-art survey of Digital Twin: techniques, engineering product lifecycle management and business innovation perspectives. Journal of Intelligent Manufacturing, 31(6), 1313-1337.

[20] Zhang, C., Sun, Q., Sun, W., Mu, X., & Wang, Y. (2021). A construction method of digital twin model for contact characteristics of assembly interface. The International Journal of Advanced Manufacturing Technology, 113(9), 2685-2699.

[21] Camposano, J. C., Smolander, K., &Ruippo, T. (2021). Seven metaphors to understand digital twins of built assets. IEEE Access, 9, 27167-27181.

[22] Edirisinghe, R., & Woo, J. (2020). BIM-based performance monitoring for smart building management. Facilities.

[23] Greif, T., Stein, N., &Flath, C. M. (2020). Peeking into the void: Digital twins for construction site logistics. Computers in Industry, 121, 103264.

[24] Hasan, S. M., Lee, K., Moon, D., Kwon, S., Jinwoo, S., & Lee, S. (2022). Augmented reality and digital twin system for interaction with construction machinery. Journal of Asian Architecture and Building Engineering, 21(2), 564-574.

[25] Pärn, E. A., &de Soto, B. G. (2020). Cyber threats and actors confronting the Construction 4.0. Construction 4.0, 441-459. [20] AnshulAgarwal. (2022). How Digital Twin is transforming the manufacturing industry.https://www.industr.com/en/how-digital-twin-is-transforming-the-manufacturing-industry-2637054.

[26] Rasheed, A., San, O., &Kvamsdal, T. (2020). Digital twin: Values, challenges and enablers from a modeling perspective. Ieee Access, 8, 21980-22012.

[27] Opoku, D. G. J., Perera, S., Osei-Kyei, R., &Rashidi, M. (2021). Digital twin application in the construction industry: A literature review. Journal of Building Engineering, 40, 102726.

[28] Anje Marjorie Anderson, Andre Van der Merwe. Time-driven activity-based costing related to digital twinning in additive manufacturing. The South African journal of industrial engineering. Vol 32, No 1 (2021).