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Paradigm of Digital Twin Application in Project Management in Architecture, Engineering and Construction

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***Abstracts*—**With the growing trend of adoption of advanced technologies like, building information modeling, artificial intelligence, wireless network, the collaboration and integration of these technologies into digital twin become more prominent in architecture, engineering and construction (AEC) industry in view of the nature and scale of AEC industry which efficiently adopted the digital twin. Digital twin is provided to be effective for AEC professions for design and project management. The digital concept is continuously developing and it is vital for AEC professionals and other stakeholders to understand the digital twin concept and the adoption of various advanced building technologies related to the AEC industry. This paper is to review the application of digital twins application in project management in AEC industry and highlight the challenge of AEC partitioners faced by the revolution of technologies including digital twins and building information modelling (BIM) for further research and future study.

***Keywords*—**Digital Twin, AEC, building information modeling, project management, internet of things.

I. Introduction

THIS paper will focus on the popular types of digital twin in AEC which are used to virtually replicate the elements of a production system. New buildings are now equipped with a series of sensors i.e., Internet of Things (IoT) devices which lead to the buildings appear to be fully automatized as Smart Building and the stakeholders in AEC industry now also show a growing interest in deploying Digital Twin (DT) of Smart Buildings. DT is set as a set of data which can describe the state of a system, and its evolution over time. The advancement of development of Internet of Things (IoT) and Building Information Modeling (BIM) can facilitate the collaborative work in both construction and evolution building's phases which is accelerating the better achievement of DT in the AEC industry. In practical, Smart Buildings are complex which require higher cost investment to achieve and build. They also require many different expertise of AEC professionals who have been trained and well understood the new technologies and the concept of information and communication technologies (ICTs), BIM, IoT, DT and life cycle management. Integration of BIM tools like BIM with IoT based wireless sensor networks intentionally designed for environmental monitoring and emotion detection can provide insights into the comfortability level.

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II. History of DT Technology

The idea of DT technology was first evoked in 1991 and the idea is that a digital equivalent to a physical system could be created through the sharing of information and data. Eventually, the National Aeronautics and Space Administration (NASA) recalled the concept in a technology roadmap in 2010.

NASA is the first to use the DT technology as the core idea and means of studying a physical object during its space exploration missions in the 1960s. NASA used the DT models from earth to control and run simulations of their spacecraft for accurate mapping.[18], [20], [21]

III. History of BIM Technology

The concept of BIM first existed since the 1970s and BIM is designed as a digital platform to keep the accurate and interoperable record of building information in order to achieve and enhance the planning, construction and maintenance over the whole life cycle of a building. [41] The other benefits of BIM are their function and ability to embed the 3D computer aided design (CAD) model with additional data including building and material specification, time schedule, cost estimation and building maintenance management (i.e., 4D, 5D, and 6D BIM) to reduce cost by preventing mistakes in the design and construction phase. BIM is used in AEC and for design visualization, consistency, clash detection, lean construction, cost and time estimation as well as enhance stakeholders' interpretation and interchange of building information of the building project [28], [39].

Concept of BIM

A BIM represents a static simulation model of the structure/ building which is a process for creating and managing a model containing digital information about a specific asset. BIM provides a 3D visualized model for AEC professionals and other stakeholders to visualize and better understand the building projects in planning, design and construction stages.

Concept of DT

A DT is a virtual model designed to accurately reflect a physical object. Various sensors related to vital areas of functionality produce data about different aspects of the physical object's performance, such as energy output, temperature, etc. The data collected from the sensors are then transferred to a processing system and processed to the digital copy. As long as the collected data being informed, the virtual model will be used to run the simulations and study performance related issues and then possible improvements will be generated with the goal of generating valuable insights for reapplying and feedback to the original physical object.

Difference between DT and Simulations (BIM)

DT and BIM of buildings can be compared in detail based on the following aspects; application focus, users, supporting technology, software, stages of life cycle and origin.

Both simulations and DTs can utilize digital models to reproduce a system's various processes. However, DT in fact represents a virtual environment which makes it more valuable for study. The major difference between DTs and simulation is about the extent and scale of their application. The major difference of simulation and DT is that simulation usually only studies one particular process while a DT is more powerful and it can run multiple useful simulations in order to study multiple processes [4], [5].

The deficiency of simulation is that their data process is not in real time basis. With the advancement of constantly updated data combined with the advanced computing power and a better virtual environment, DTs have greater ultimate potential to improve products and processes and have the ability to study more issues as compared with simulations.

IV. DT Concept in AEC Project Management

As explained in different researches, the concept of DT is based on the development of multi-physical modeling of a complex system and incorporates with the integration of real objects for real-time monitoring [16], [30]. According to [54], the DT is also defined as a computational model of an equipment or system which can represent all the functional characteristics with linkage of the actual element. Digital representation comprised that information from multiple sources throughout the product life cycle. The information collected is then continuously updated and can be visualized in different ways to predict and simulate current and future conditions in both design and operational environments for improvement of decision making.

DTs integrate artificial intelligence, machine learning and data analytics to create dynamic digital models that are able to learn and update the status of the physical counterpart from multiple information sources [7], [34]-[36]. Basically, DT comprised the physical object, its virtual model, and the data information connections which are capable of linking up the physical and virtual objects together [44], [46]-[49]. According to [1], the three main parts of DTs are listed as:

a) Modeling: the physical and virtual models described the main characteristics of the system.[1]
b) Connection: the physical and virtual system was constantly connected with the concept composed of data transmission, conversion, storage, protection, etc. [1]
c) Advanced data analysis: the information was obtained from a database, pre-processed and exploited by data analysis techniques and artificial intelligence (AI) algorithms. [1]

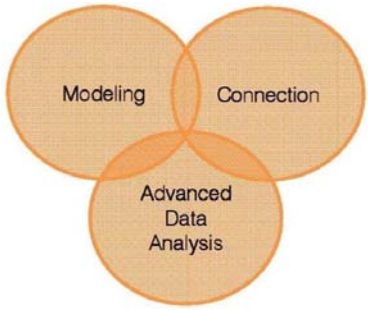

Fig. 1 Main parts of DT

The building and construction industry is open to change and embrace the opportunities that come with DT applications and other digital technologies. DT presents the opportunity to integrate the physical world and digital world, which helps immensely in addressing the challenges of building and construction industries [8].

BIM provided a digital platform for seamless collaboration and interconnection between AEC professionals. The application of BIM is also widely adopted in building life cycle assessment for design, construction process as well as operational phase [3].

Architecture and engineering plays an important role in sustainability of the building and has a significant impact on accurate choice and use of natural resources for construction material of the building [29].

Both BIM and IoT are increasingly being used in the building, construction and infrastructure industry. The revolution and adoption of technologies like BIM have significant change within the construction industry. The global BIM adoption is accelerating due to the potential and benefit of BIM adopted in the design and engineering phase to the advancement of building technology in the construction industry. The indispensable part of the DT concept is the near-real-time updates. In general, BIM can only provide static data of the built environment and is unable to update real-time information in their models automatically without the aids of additional data sources. With the evolution and development of IoT, it has the ability for interconnection of sensing devices and provides information exchange across different platforms with incorporation and integration of real-time data collected by sensors as well as the static information provided by BIM models. According to [29], the achievement of automated updating of BIM models based on real time building status requires the help of smart devices, visualization and analysis of real-time environmental data becoming available in BIM models. The benefit of integration of BIM and IoT technologies to DTs can provide a complete dutiable platform for the real-time monitoring of the construction process and building indoor environment [6], [15].

Another advanced technology called Building Lifecycle Management (BLM) plays a revolution of digital management; BLM is a strategic planning process which support the development, operation and maintenance of buildings and their associated infrastructure in building planning, design, construction, operation, and maintenance phase. The advantage of BLM is to reduce building costs and improve efficiency by ensuring that buildings are built, operated, maintained, and replaced in the most cost-effective and timely manner.

DT can be used by the architects and engineers to improve the performance of future buildings and better utilization of information for determining the directions of sunlight and wind obtained at the building facade to improve the lighting and airflow inside the building during design stage. [11] The role of DT in the construction phase is to reduce construction cost in an efficient and effective manner and also improve quality which the traditional method.

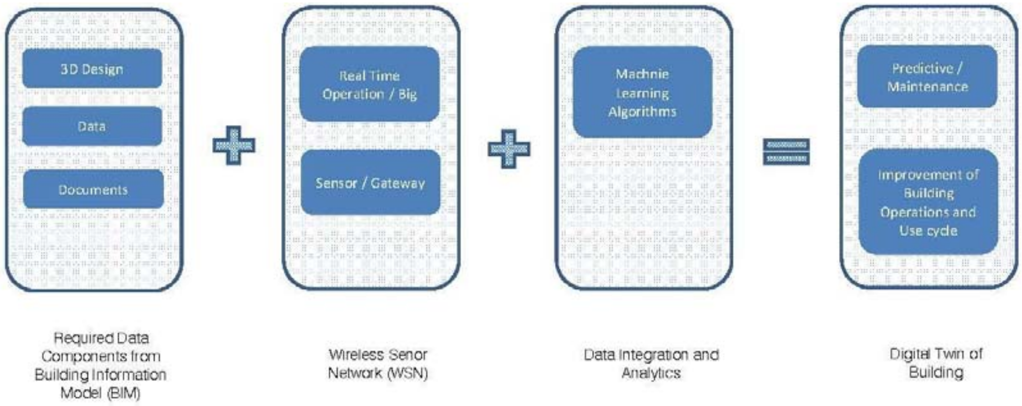

Fig. 2 Essential components to create a DT of building and difference with BIM [11]

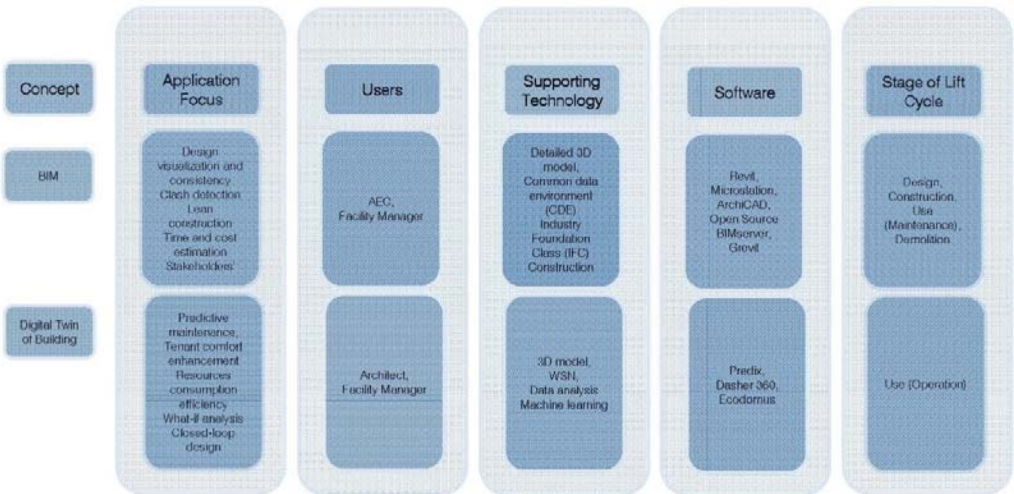

Fig. 3 A detailed comparison of BIM and DT of building [11]

DT in Architecture and Engineering Sector

BIM represents a static model of the structure/building whereas DT is an attempt to present a dynamic and responsive model. BIM, a process for creating and managing a model containing digital information about a specific asset, has aided the adoption of DT at the design and engineering phase of a project. A digital BIM model draws on information collaboratively assembled and updated at key stages of the project. BIM pulls the information from stakeholders together at the design and engineering phase and shares it to improve the overall outcome of the project. BIM models assist in solving problems among different construction stakeholders by allowing data to be added, modified and verified against real-life scenarios [13], [40], [55]. Data collected using DT can be saved in database and then used by architect and engineer during future projects. This can help in decision-making regarding material selection, energy management, procurement and supplier selection. Early design decisions relating to feasibility of project, energy analysis, sustainability issues and the like could be informed utilizing BIM and serve as pre-construction guides. The AEC stakeholders of the project could clarify their intentions and ensure effective planning, better understand the project [14].

With the implementation of BIM in Life Cycle Assessment (LCA), architects and engineers can focus more on estimating CO_2 emission, environmental impact and energy consumption by using BIM software and automated integration of different data during design stages. [29] Integration of BIM into IoT under DT, DT allows AEC professions to carry out energy planning at design stage for achieving low carbon output. Other than the determination of building geometry for the simulation, daylighting performance simulation and analysis, BIM can provide those required information like building materials which can assist the architect and engineer to improve the simulation efficiency and accuracy significantly. BIM provides the opportunities for architects and engineers by comparison of different scenarios and simulating the relationship between energy consumption and building design parameters to facilitate the decision making during concept design stages [29].

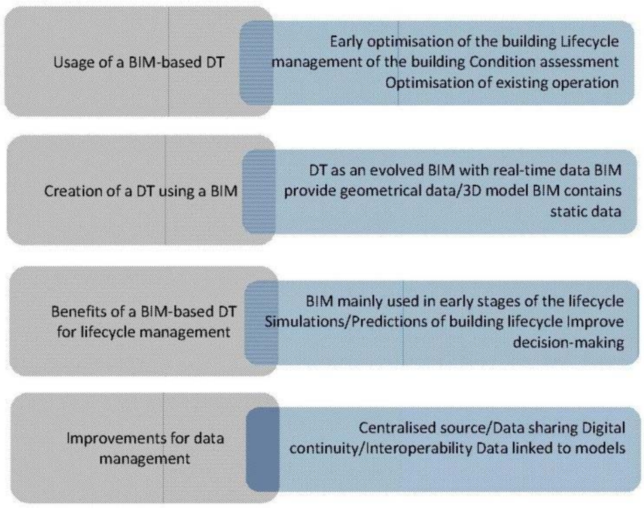

Fig. 4 Benefit using BIM as a basis for creating a DT for AEC industry [12]

DT in Construction Sector

The DT concepts can be transferred to the production of precast concrete element in the construction industry. The study established that real-time networking of products, processes, and systems which are based on consistent data were necessary for innovative adaptive modular construction activities. DT can help with a considerable amount of data to reduce construction cost, improve quality and enhance effective stakeholder management by providing stakeholders with ample information about the project. In the construction phase, DT can also assist in various management activities including resource management, materials management, schedule management, quality management quality where product and design defects are analyzed and predicted during manufacturing. The other related technologies in DT like GPS, smart sensors and sensor networks can assist locating and measurement of work done, tracking of production progress, tracking materials and worker locations, and monitoring construction quality.

With the increasing of adoption of BIM in AEC industry, BIM is now being recognized as a reliable approach for sustainable construction particularly for environmental, economic, and social dimensions aspects. The capabilities of BIM in the energy efficiency of building structural systems also enhanced the future sustainable decision-making of building structures with the balance the energy efficiency and engineering performance indexes [19], [22], [29].

Since BIM is designed in 4D simulation, it also improves the management efficiency of modular construction projects and significantly reduces the construction time as well as training through providing the visualization information [29].

In post construction stage, DT technology is applied in facilities management, maintenance management, monitoring, logistics processes, enhancement of tenants' comfort, what-if analysis for optimization of the building design, and energy simulation of the project [23], [24]. DT can provide facility managers the opportunity to make critical decisions regarding building operation and maintenance, building performance management, and building energy consumption optimization. It improves the project’s operational efficiency through the collection of real-time data which aids predictive maintenance and ensures well-informed decision making. DT also provides potential for monitoring the ambient temperature and humidity of the working spaces, maintenance planning optimization by using data from the building management systems and failure/ maintenance logs and allocating resources by prioritization of the maintenance tasks. To achieve efficient and sustainable buildings successfully, the key factors of real-time energy evaluation, indoor environment monitoring, indoor thermal comfort, space management, hazard monitoring in building management became very crucial.

Benefit of DT in Project Management in AEC Industry

DT is synonymous to a BIM model within the AEC industry. Architect, engineer, project manager and others involved in building project planning activities are significantly assisted by the use of DTs. There are three main key areas which gain benefits from DT including the following:

1) Enhancement of R&D: Using DTs can facilitate more effective research and product design with the valuable data created about likely performance outcomes. The information can lead to insights that help companies make needed product refinements before starting production.
2) Increase of Efficiency: DTs can help mirror and monitor production systems with a virtual monitor achieving and maintaining peak efficiency throughout the entire manufacturing process.
3) Product End-of-life: Architects, engineers and manufacturers can make use of the advantage of DT to decide the most effective products which can reach the end of their product lifecycle and the need to receive final processing through recycling and determine which product materials can be harvested [33], [51], [52].

Benefits of adoption of DT and BIM in AEC industry are listed below:-

a) BIM enables the architect and engineer to achieve project quality enhancement, accurate timetables scheduling, and total project costs reduction [42], [43].
b) BIM has been used for generating and managing parametric models of buildings for document errors and rework reduction. AEC professions can review the digital model instantly and reduce the time for design. It enables digital model creation, construction design, operation management of the construction process, and project life management achievement [9], [31].

c) Global Positioning System (GPS), computer vision, tag identification systems, smart sensor networks, communication networks, etc., produce information which enhances construction monitoring.
d) Application of DT can transform a smart and lean construction processes towards a smart project life cycle management.
e) DT and Mixed Reality (MR) technologies can help address these limitations by enhancing human-robot interaction, for on-site construction processes [10], [25], [50].
f) DT can be used for product life cycle management [45].
g) Data in the DT of construction processes can be used for process tracking and project monitoring purposes [44]. The live data obtained from the DT can include any sensor data that are obtained in real time [38]
h) Architect and project manager can simultaneously monitor different zones or locations of the construction site enabling them to multitask more efficiently. The progress of the construction can be monitored completely remotely and the AEC professions can have the opportunity to know the status of construction while remaining in an office far away from the construction site
i) The DT models allow engineer and operator to achieve better transportation management, energy usage optimization, asset anomaly detection, resource and logistics planning, safety monitoring, event prediction, and running simulations [17], [32], [53].
j) The DT models could be used within a smart city which facilitates connectivity using IoT devices. This helps the engineer and operator to enhance the services, utilities and infrastructure by testing various transportation scenarios [2], [26], [37].
k) As-built BIM models for facilities management are intended to provide information regarding the status of buildings when commissioned.
l) DT models can be used for prefabricated construction including modular integrated construction (MiC), design for manufacture and assembly (DfMA) and prefabricated prefinished volumetric construction (PPVC) [27].

Future Growth of DT in AEC Industry

The rapid expansion of the DT market indicates that DTs are already in use across many industries. AEC industry achieved the greatest success with DT as it is involved with large-scale products or complex projects. It is worth from a financial point of view to invest significant resources in the creation of a DT. According to the data released in [21], the DT market was valued at USD 3.1 billion in 2020 and the industry analysts also speculated that the market could be continued to rise sharply to about USD 48.2 billion in 2026 [21]. The adoption of end-to-end DT in AEC project management will let AEC stakeholders reduce their construction downtime while upping production.

V. Conclusion

In view of the fundamental change to existing operation models in AEC industry, digital reinvention is occurring in asset-intensive industries that are changing operating models in a disruptive way. An integrated physical plus digital view of assets, equipment, facilities and processes is required. DTs play a vital part of this realignment and the future of DTs is unlimited as the increasing amounts of cognitive power are constantly being devoted to their use. DTs are capable to learn new skills constantly and increase their capabilities. It is undeniable that DT can satisfy the stakeholders' need for better products and make the processes more efficient. Learning from this literature review and research would help AEC professions and stakeholders to prepare and tackle the impact of the revolution of the AEC industry on transforming asset operations with DTs.

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