Digital Twin Technology as a Paradigm for Smart Management in the Built Environment

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Abstract The 21st-century industry world is constantly seeking diverse ways to shrink costs and time while boosting productivity and efficiency. Utilising digital twin technology is a veritable means of achieving that in the building sector. This will help better predict the future, enhancing decision-making and, in turn, reducing operational cost and downtime while simultaneously enhancing building efficiency and productivity. This study, therefore, investigates ways that digital twin technology can be used to make facility management systems proactive in nature. The study is designed to follow a methodical review of literature. It draws relevant data and information from extant studies conducted on digital twin technology within the built environment field as well as the entire field of science, technology, and engineering. A framework for management was conceptualised through this research and named 'Digital Twin Based Smart Management Plan'. A strategic process for the Smart Management Plan was developed and classified into initiation, modelling, utilisation and reuse phases. The Digital Twin-Based Smart Management Plan framework ensures complete interaction among the process, people, place, and device.

Keywords Digital twin · Cyber-Physical Systems · Facility management · Building Automation Systems · Building management

1 Background to the Study

In the recent past, studies have suggested that the building industry is static regarding technological innovations. However, lately, contemporary technologies are beginning to emerge within the industry, which is a welcome development and a forward push

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on the right track towards enhancing productivity and sustainable development [1]. A major factor for the motivated adoption of digital twin technology is its multi-faceted industry relevance. This relevance encompasses the engineering, production, and operation of industry-level systems which can only be achieved through a complex interrelationship of different fourth industrial revolution technologies that have graced the twenty-first century [2]. Numerous fields are beginning to intellectualise the application of digital twin technology to specific areas. Generally, it is used to pre-empt complications and optimise system efficiency [3]. With its pioneer success in the aeronautic industry, digital twin became a key paradigm in the era of industry computation and the fourth industrial revolution [4]. The building industry should not be left out of this technological advancement. There is a need for the building industry to take advantage of the digital twin technology and use it to optimise the numerous aspects of a facility's life cycle from conception to deconstruction.

Over time, various ICT-aided systems have been utilised for FM practices; however, most have been deemed less efficient owing to the fact that they do not support easy information exchange, which delays decision-making [5, 6]. It is worth noting that building information modelling (BIM) was developed to better manage the facility life cycle. BIM creates a model of individual building components, including the interactions with the external environment. All physical information and restrictions of the building or facility are included in the model [4]. A significant limitation of the BIM system is that it cannot offer information in real time for immediate operational action. As opposed to BIM, which centres on buildings, digital twin modelling is a more intelligent and sophisticated building model focusing more on human interactions with buildings through real-time data collection and transmission on the building's present condition. Over time, a building's digital twin will evolve in response to the physical change in the building throughout its life [7].

The 21st-century industry world is constantly seeking diverse ways to shrink costs and time while boosting productivity and efficiency [8]. Utilising digital twin is a veritable means of achieving that in the building sector. It is equipped to create an alternate virtual building and the facilities contained therein and then subject it to different real-life situations and occurrences through simulations. This will help in better prediction of the future, which will enhance decision-making and in turn, reduce operational cost and downtime while simultaneously enhancing building efficiency and productivity. From the above discussion, it is evident that the established management system in the built environment for facility management is reactive in nature – it attends the situations as they occur, increasing maintenance costs and downtime. There is a need for management systems to be proactive – they should predict and find ways to mitigate problems before their occurrence. This study, therefore, investigate ways that digital twin technology can be used to make facility management systems proactive in nature.

The research study ultimately aims to establish a smart management plan for buildings and facilities using digital twin. The study intends to revolutionise management practices to meet up with the fourth industrial revolution in the 21st-century world.

2 Methodical Structure of the Study

According to the research motivations outlined in the introduction, this study aims to develop a digital twin-based smart management plan for buildings and facilities. This effort will investigate how digital twin technology can be utilised to create proactive facility management systems. In order to accommodate the fourth industrial revolution of the twenty-first-century world, building management practices must be revolutionised. This study was conducted using reviews from relevant literature published on digital twin, facility management, building management systems and the built environment.

The methodology employed is a comprehensive and methodical literature review on the concept and its application to management practices in the built environment. In particular, a search was conducted in the Scopus Database for all publications published between 2015 and 2020 that included a combination of the terms "Digital Twin" and "Buildings" or "Built Environment" or "Infrastructure" or "Facility Management" in their titles, abstracts, or keywords. The only language considered was English; the type of publication (journal articles, conference papers, etc.) did not matter in the selection for inclusion. The reason for excluding publications before 2015 was that the main focus of the study was the application of Digital Twin to the built environment in relation to the fourth industrial revolution. No relevant publications are to be found prior to the year 2015 with respect to these topics. The study also reviewed extant archived literature from other sources to develop sufficient background knowledge for the evolution of digitalisation within the built environment.

The paper is structured as follows; Sect. 1 constructed a background to the study that developed to highlight the aim of the research. Section 2 discussed the structure which the study followed. Section 3 discussed the concept of digitalisation and digital twin. Section 4 extensively reviewed the leap from BIM to digital twin. Section 5 explored how built environment assets and facility management systems can be improved through digital twin. Section 6 explored previous use of digital twin for building and facility management. Section 7 developed a framework for facility management using digital twin, this is themed digital twin-based smart facility management. Section 8 describes the strategic process of the smart management plan. Section 9 concluded the study, highlighting the major findings of the study.

3 Digitalisation and Digital Twin

Digitalisation in industry sense has evolved across four phases. The first is digital enablement which involves the invention and usage of computers for scientific computing, it essentially entails converting physical documents into virtual formats. Digital assistance involves using computer-aided applications and systems to ease and efficiently perform tasks. Digital interlinks and control which involve the use of the internet to ease communication. Lastly, cyber-physical interlinkages encompass the use of new generation technologies such as AI, IoT, big data, cloud computing, digital twin, etc. to ease industry level activities [3, 9]. Figure 1 shows the evolution of digitalisation highlighting the processes and timeline.

Digital twin technology was birthed in 2010 when the United States National Aeronautics and Space Administration (NASA) focused its research on adopting the technology and its operation as their technology strategy for the future exploration of space [10, 11]. With its pioneer success in the aeronautic industry, digital twin became a key paradigm in the era of industry computation, the internet of things (IoT), and the fourth industrial revolution in general [4].

Studies have noted that digital twin is dynamic in nature as it is the basis of cyber-physical technology. Digital twin refers to a physical asset and a digitised model of that asset that can intercommunicate through forward and backward interactions in order to co-progress in unison [13]. Modern technologies in digitisation have allowed the holistic collection and storage of data from the physical asset to ensure accurate conformity of the virtual model in real-time [14].

The value of digital twin to the world is almost immeasurable since the technology devises a dynamic means to replicate models of physical assets in a virtual form. This replication conforms to the physical structure, position, situation, arrangement, attitude, condition, and kinesis [12]. A true replication of the physical world in digital form can be achieved through sensor-based data gathering, 3D computing, big data statistics, artificial intelligence and machine learning. This system can then be used

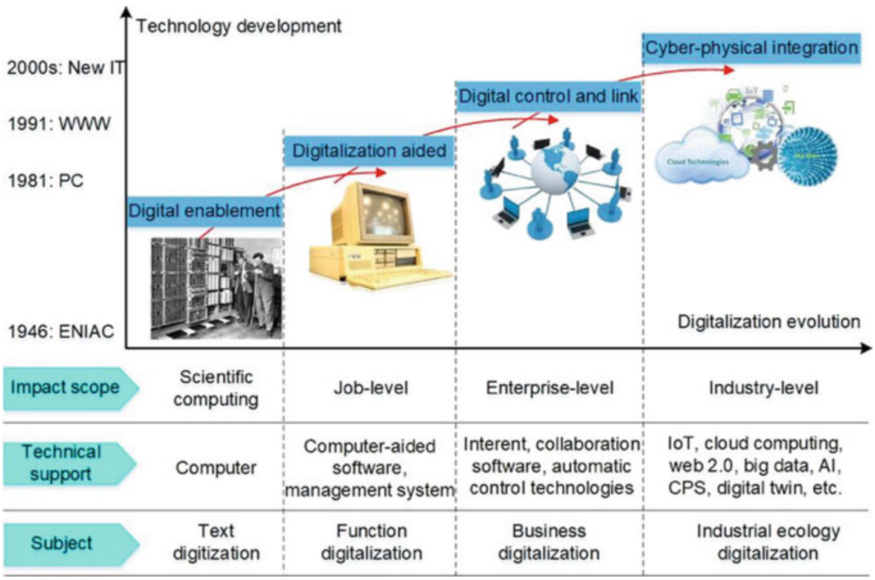

Fig. 1 Process of digitalisation [12]

for various activities, including system observation, diagnosis, forecasting, as well as enhancement.

Digital twin can specifically aid in decision-making in numerous industry fields since it can examine current trends, analyse past challenges, and project future uncertainties [15]. Also, both operational and administrative, orientation, training, and development of workers, can be performed through virtual models that the digital twin offers since the model is a true representation of the physical structure, attributes and behaviour of a real-life asset in real-time [16].

Digital twin also aids in understanding complex systems and procedures as it can use simulation and virtual reality means to breakdown physical assets and process them into smaller manageable parts [12]. A more advanced benefit of digital twin is the collection and digitisation of industry experts' knowledge, capabilities, and experience. This knowledge is stored and can be conveyed and modified to mitigate the knowledge gap in a particular field [12].

There are five aspects of digital twin: physical entities, virtual models, twin data, services, and connections. Physical entities are the assets in the physical world for which virtual models are to be created. Virtual models are the true digital duplication of the physical entity in real-time [13]. Digital twin data is the force behind the technology. The data are usually in multiple dimensions and are heterogeneous in nature. While some are sourced from the physical assets, others are formulated by the digital models through simulation. Data could also be sourced from the system's process and expert's knowledge [17]. Digital twin services encompass the wide array of activities that can be accomplished through the digital twin technology. These activities might include observation, diagnosis, forecasting, management, and enhancement. And lastly, digital twin connections refer to the interlinkage between the physical assets and their virtual replicas as well as the data and services. The connection allows efficient operation, complex analysis, and multifaceted simulation. There are six facets of connections in digital twin technology; each interlinks the other four dimensions pairwise [12, 13].

4 The Leap: From BIM to Digital Twin

The recent trends of incorporating IoT-powered sensors into built environment facilities has given unfettered opportunities to acquire building performance, management, and maintenance data in real time. And when this data is subjected to appropriate analysis and simulation, it would be useful in enhancing the operational efficiency of the components that makes up the built environment. It is worth noting that smart and intelligent buildings and, by extension, smart and intelligent cities require unrestricted access to data and processed information to function efficiently. Therefore, it is safe to assert that digital twin is a vital step to efficiently and sustainably attaining smartness in the built environment [18].

The application of digital twin technology to the built environment field will enhance the design process, optimise building operation in relation to the external

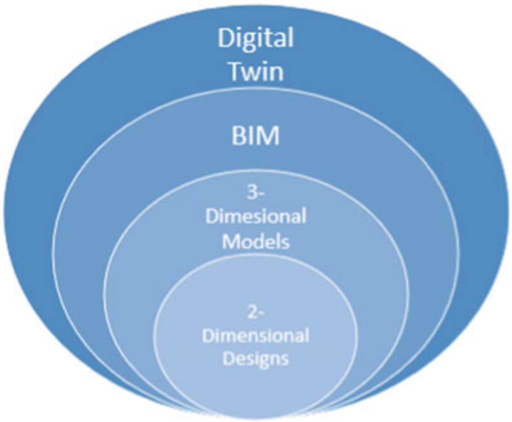

Fig. 2 Evolution of digital construction designs and models [19]

environment and also improve failure and fatigue prognosis [11]. Currently, numerous research studies are ongoing to improve modelling and simulations in built environment assets. The outcome of these studies will be channelled into strengthening digital twin applications in the built environment [19]. In construction engineering, digital building designs have gradually evolved from 2 and 3-dimensional designs to building information modelling, as shown in Fig. 2. However, it is important to note that building information modelling is the basis of digital twin in the built environment [19].

The concept of building information modelling entails accurately designing a 4 or 5-dimensional model which is diametrically for a proposed building or facility. All attributes of the proposed construction project are incorporated into the model, and the extent of the individual attributes is determined by associated physical boundaries [20]. A model of individual building components is created and their interactions with the external environment through BIM. All physical information and restrictions of the building or facility are included in the model. They can be subjected to trackable changes since the model is collectively created for different built environment professionals through the use of sophisticated architectural ICT tools (Jung, 2017). Figure 3 reveals the transformation of BIM into digital twin. Recent practices have seen the introduction of BIM integrated complementary technologies like Geographic Information Systems (GIS), Computer-Aided Facility Management (CAFM), Construction Project Management (CPMS), and Computerized Maintenance Management System (CMMS) [4].

BIM models the design of buildings and facilities in which individual building components are created and their interactions with the external environment. All physical information and restrictions of the building or facility are included in the model [4]. A significant limitation of the BIM system is that it cannot offer real-time information for immediate operational action. As opposed to BIM, which centres on buildings, a digital twin is a more intelligent and sophisticated building model that focuses more on human interaction with buildings through real-time data collection

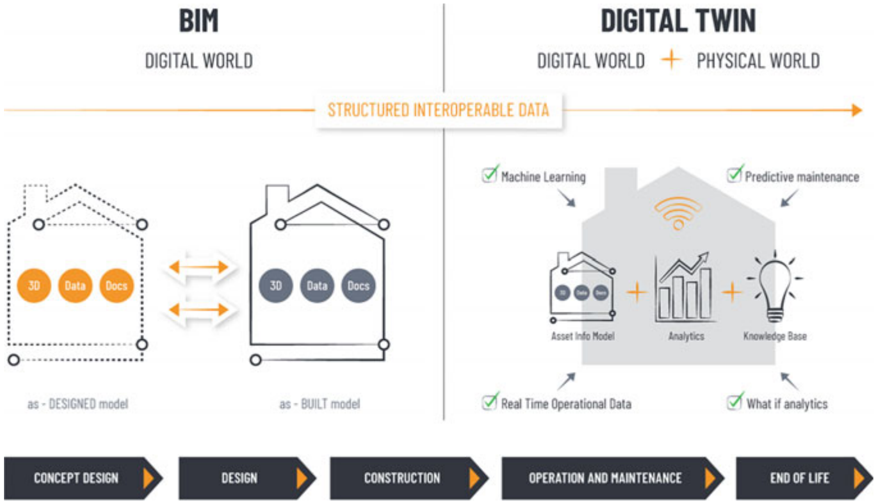

Fig. 3 BIM and Digital Twin Model Building

and transmission of the building's present condition. Over time, A building's digital twin will evolve in response to the physical change in the building throughout its life [7].

Digital twin in the built environment encompasses the design, construction, and operational stages of the building. Hence, Rogers (2019) termed digital twin as 'BIM on steroids', explaining that technology's possibilities in the built environment are currently boundless. Despite the sophistication of the BIM system, there are scores of construction information that transcends the scope of BIM, which digital twin in the built environment addresses. Building information modelling (BIM) can be revolutionised into digital twin for the built environment, which introduces dynamic elements. These elements include IoT integration in buildings and infrastructures, automation in construction, and building management systems. These elements help collect, collate, store, analyse, simulate and disseminate vital building information [4].

5 Facility Management and Digital Twin

The building and real estate field of study has always received profound interest from various professional fields, including architecture, cartography, economics, engineering, law, and management [22]. In essence, a building as an asset can be assessed from different viewpoints. As an element of science, buildings encompass all physical attributes and the legal, economic, and institutional interest inherent in them. Similarly, contemporary property management points to the fact that buildings should not merely be regarded as being only a physical entity but also as a medium of fulling management objectives [22].

Noor & Pitt (2009) reported that the intention of facility management from an economic perspective involves improving productivity and organisational revenue, which is accomplished by continuously creating avenues for cutting costs through executing a series of processes that are in line with achieving organisational goals. Effectively managing a building and the facilities contained therein usually involves verities of professionals who are required to work in concert with each other to achieve facility management objectives [6].

Traditionally, numerous professionals, managers, and artisans of varying specialised disciplines are involved in executing facility management activities. With the considerable number of personnel usually involved, efficient information exchange and management systems are required for efficient building and facilities management [24]. Incorporating information technology into facility management has offered various opportunities, which entails a more thorough analysis of day-to-day building operations. These operations include prompt estimation and identification of defects; better risk management practice; better estimation of potential operational system failures, and improved avenues for the safety of lives and property [25].

Over time, various systems have been utilised for facility management practices, which include Building Automation System (BAS); Computer-Aided Facility Management (CAFM); Computerized Maintenance Management System (CMMS); Energy Management System (EMS); Electronic Document Management System (EMDS) [5]. Practical and research evidence has confirmed the usefulness of these systems. However, they do not support easy information exchange, which delays decision making and causes unwarranted actions or inactions, making these ICT-aided systems less than efficient for facility management [6]. The development of BIM was a game-changer for the building sector, especially in facility management. A more efficient documentation and information conveyance system was utilised to improve the management of facilities [25].

The ideology behind digital twins is developed based on previous concepts and technologies. From a generally accepted perspective, digital twin is seen as a new-age Building Information Model incorporated with internet-supported sensors to ensure a real-time model update through data transfer from the building. The data collected and transferred in real time must be interpreted through analytics and AI in order to enhance decision-making [26]. For facility management, digital twin can be applied to making operational decisions and organising maintenance, remodelling, and upgrading. A digital twin platform can serve as a communication interface between the stakeholders during any stage within the facility's life cycle. Digital twin will ensure that interactions between building stakeholders are effective and help decrease unnecessary red tapes, rework, and energy demand [4].

6 Previous Use of Digital Twin for Facility Management

There are two identified existing models related to the study. As shown in Fig. 4, the first was developed by Nasaruddin et al. (2018) and was named 'Conversion of physical room to its digital representation'.

This model shows that there are seven distinct hubs, which all emanate from the building manufacturer's specifications. The framework indicates that the building manufacturer's specification is used to produce the physical space for which the digital twin is required. Data from the physical space are gathered through sensors, and these data are subjected to analytical algorithms that simulate visual representation. This representation is directly transmitted to the user interface, which shows the digital twin representation.

The second model related to the study was developed by Nie et al. (2019) and was tagged 'Digital twin-based building management service and prediction model'. The model consists of four hubs: physical building, digital twin, building operations service, and building prediction service platform; these are shown in Fig. 5.

The physical building is the primary source of data within the system, which are transmitted in real-time. The building's digital twin hub is the virtual building, which integrates models to create a digital replica of the physical building. Simulation results are derived and transmitted from this hub.

The building operations service hub incorporates a cluster of new-age technologies needed to observe, forecast, and properly manage a facility. It incorporates the management service hub and the predictive service hub. The big data process uses a collection of applications to proactively predict unforeseen interference with the operations of the building. This prediction can optimise decision making to improve building management and performance.

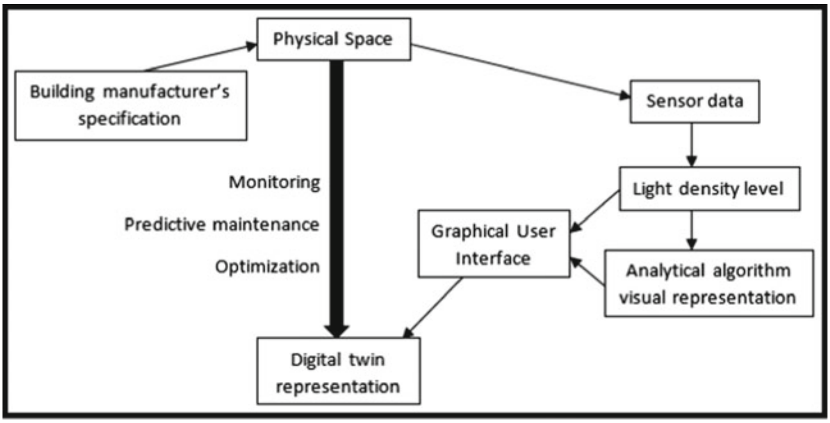

Fig. 4 Model for the conversion of a physical room to its digital representation

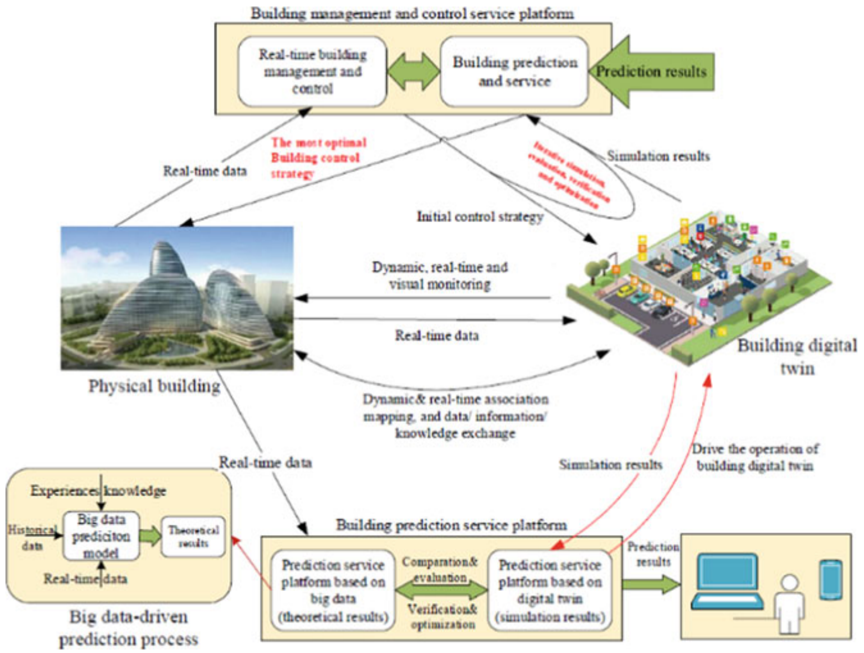

Fig. 5 Model for the conversion of a physical room to its digital representation

7 Digital Twin-Based Smart Management Plan

A critical review of both identified existing models related to the proposed study revealed some issues that need to be addressed. Both models did not account for the collation and storage of data gathered by the system. The storage of such data is vital for big data analytics and future simulations. Furthermore, the models did not consider benchmarking standards already established for both basic and ICT-aided facility management. Lastly, both models did not consider the importance of user perception and feedback systems; however, to ensure efficiency, there is a need to gather feedback from users. All these were taken into consideration when conceptualising this research and included in the model named Digital Twin Based Smart Management Plan, as shown in Fig. 6.

The Digital Twin Based Smart Management Plan consists of eight hubs. The virtual replica is a digital representation of the physical building which allows for real-time data exchange and visual monitoring. Data from the virtual hub is subjected to big data analytics and results are applied to the data obtained from the physical building as well as simulation results to optimise facility management practices. In addition, historical data and feedback from users of the smart management plan also make up inputs to the optimised management practices. At the apex, the smart management plan is a product of optimised management practices, historical data, and benchmarking standards for facility management. Finally, the perception

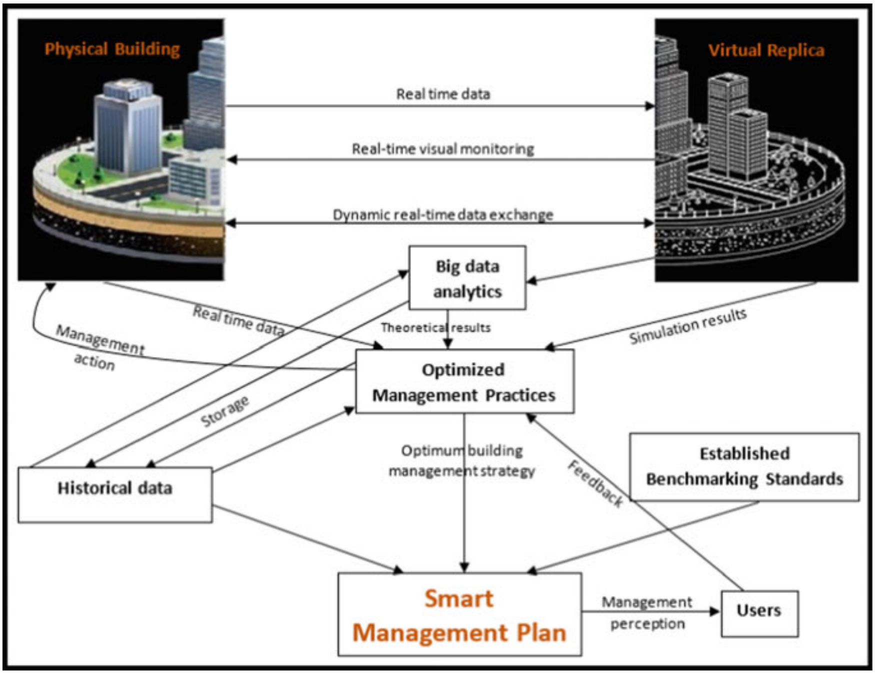

Fig. 6 Digital twin-based smart management plan

of facility managers who are the users of the smart management plan are recorded and feedback backs are offered back into the system to continually optimise management practices. This model ensures complete interaction among the process, people, place, and device.

8 Strategic Process for the Smart Management Plan

The digital twin based smart management plan can be implemented in four phases. These follows the principles of creating a digital twin. This strategic process is represented in Fig. 7.

The first phase of the process is initiation. The initiation phase entails defining the product's scope, the building's digital twin. The digital twin-based smart management plan includes monitoring various parameters that help in predictive maintenance, developing a business model to schedule predictive maintenance better, and developing a financial model to help reduce maintenance costs. The initiation phase also entails defining the requirements of the digital twin model. The requirement must cover data collection from the building and mode of sorting and analysing the collected data.

Fig. 7 Strategic process for the smart management plan

The second phase of the process is modelling. Modelling entails creating a definite and exact virtual twin model of the physical building. The modelling phase also entails linking the modelled virtual twin with existing data & systems of the building. This includes the interactions and functionalities of the building and its environment. The third phase of the process is utilisation. Utilisation entails developing effective and efficient communication between the physical building and its virtual twin. This will involve establishing connecting protocol and standards, security, middleware, Storage, and data analytics based on user interface needs. The fourth and final phase of the process is reuse. The reuse phase entails establishing an efficient information management system to create a platform for easy reuse of all collated and analysed data.

9 Conclusion

The 21st-century industry world is constantly seeking diverse ways to shrink costs and time while boosting productivity and efficiency. Utilising digital twin technology is a veritable means of achieving that in the building sector. This will help in better prediction of the future, which will enhance decision making and in turn, reduce operational cost and downtime while simultaneously enhancing building efficiency and productivity. This study, therefore, investigates ways that digital twin technology can be used to make facility management systems proactive in nature.

A framework for management was conceptualised through this research and named ‘Digital Twin Based Smart Management Plan’. The Digital Twin-Based Smart Management Plan consists of eight hubs. The virtual replica is a digital representation of the physical building, allowing for real-time data exchange and visual monitoring. Data from the virtual hub is subjected to big data analytics, and results are applied to the data obtained from the physical building as well as simulation results to optimise facility management practices. In addition, historical data and feedback from users of the smart management plan also make up inputs to the optimised management practices. At the apex, the smart management plan is a product of optimised management practices, historical data, and benchmarking standards for facility management. Finally, the perceptions of facility managers who are the users of the smart management plan are recorded, and feedback are offered back into the system to continually optimise management practices. This framework ensures complete interaction among the process, people, place, and device.

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