Digital Twin-based Framework for Green Building Maintenance System

W. Wang[1], H. Hu[1], J. C. Zhang[1], Z. Hu[1]
[1]School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, China
(hhu@sjtu.edu.cn)

Abstract - **This study analyses the characteristics and theoretical basis of green building maintenance system (GBMS) and proposes a digital twin(DT)-based framework for GBMS (DT-GBMS). This framework helps operation teams solve the problem of insufficient informatization and automatic management ability of green building maintenance. Besides, the structure of DT-GBMS is designed in detail according to practical usage. Finally, a prototype based on Bentley Systems software is developed by using 3D laser scanner and sensors to verify the feasibility of the proposed framework. The results indicate that the DT-GBMS can reflect the accurate and real-time status of green buildings and is able to improve the efficiency of green building maintenance by automatic management.**

Keywords - **Green building, Digital twin, Maintenance system**

I. INTRODUCTION

Many countries around the world pay close attention to green building in order to achieve the ecological goals of reducing pollution, protecting the environment and conserving resources, and to provide healthy space for people to use. Whereas in practice, many green buildings lack accurate real-time data to reflect the actual operational status of buildings and support efficient maintenance management, which often fails to achieve the expected goals, although these building are designed according to the green building standards, and have obtained relevant identification certification [1]. Therefore, to improve the ability of informatization and automatic management of green building is worthy of academic attention.

Previous researches about green building maintenance system (GBMS) mainly focus on informatization management which refers to automatic collection and digital presentation of facilities' operational data, but give limited consideration to automatic management [2, 3]. That is, the system can automatically make a primary decision on part of the data, and output control instructions. Meanwhile, the green buildings can be directly controlled by operating the system. Furthermore, existing studies have not paid enough attention to the problem of "data island" in building operation management, which refers to how to effectively read and write heterogeneous data from multiple sources, including multiple vendors and multiple systems, and in multiple formats [4, 5].

In recent years, Digital Twin (DT) technology has been developing rapidly in many industrial fields. Briefly, digital twin refers to creating a virtual model of a physical entity in a digital way, a perfect mapping of the entity [6]. It can not only simulate the behavior of the physical entity based on real-time status data, but also make operational instructions to the entity, so that the product can be controlled under guidance. Hence, this study proposes a digital twin-based framework for green building maintenance system (DT-GBMS) to establish a GBMS with standardized data management and automatic management capabilities, aiming to improve the efficiency and quality of green building maintenance through technical upgrading and process optimization.

II. ANALYSIS OF THE CHARACTERISTICS OF GBMS

Green building maintenance is a new property management method which is based on the traditional property service and integrates appropriate new technologies and the concept of sustainable development [3]. Hence, GBMS has the following characteristics:

1) *Complexity*: For one thing, the realization of GBMS's functions is complicated, because green building maintenance involves the daily management of water supply, drainage, gas, electricity, telecommunications, security, and fire control, etc. For another, the information space of GBMS is complex, because the system involves various target objects such as personnel, equipment, environment, etc., and the monitoring of these objects produces a large number of data or commands, which exist in decentralized parts of the system.

2) *Heterogeneity*: The facilities of large green buildings are diverse and the system's functions are complex, which makes GBMS heterogeneous. Hence, it is required that GBMS can support cross-platform transactions and be compatible with multi-vendor, multi-system, multi-format heterogeneous data, so that GBMS can integrate multiple subsystems with different functions and structures.

3) *Autonomy*: GBMS helps staff have a real-time understanding of the building's status to timely find out the existing problems and give feedbacks. Meanwhile, through mining and analyzing accumulated data, the abnormal

This paper is supported by the National Key Research and Development Program of China (Grant No. 2018YFC0705900).

status of the facilities can be found in advance, so as to improve the operation scheme of the building. Therefore, GBMS not only needs informatization maintenance, but also autonomous functions to reduce the workload of staff.

4) *Data-driven*: GBMS needs to collect lots of status data of the building, and it also generates vast amounts of data in the process of system calculation, decision making and implementation. Furthermore, the system consists of several subsystems, some of which are driven by mathematical models. Hence, compared with the traditional model-driven approach, the data-driven approach is more suitable for the characteristics of GBMS, which can more effectively improve the efficiency of building's massive mine data.

III. DT-GBMS

A. Theoretical basis

The aim of DT-GBMS proposed in this study is to realize the real-time interaction between physical entity and its virtual model, so as to achieve the goal of intelligent green building management. Briefly, the theoretical basis of DT-GBMS consists of three parts, namely virtual twin, prediction twin and control twin. Firstly, virtual twin means that the virtual model can perfectly map the physical entity, as indicated in TABLE 1. Interactions with the physical entity can be obtained through virtual twin. For example, a virtual model can be used to inquire or control a facility in response to its status.

TABLE I
THE CONCEPT OF VIRTUAL TWIN

Dimension		Description
Static state	Shape	Resemble each other on the external surface
	Structure	Resemble each other on the internal structure
	Material	Resemble each other on the constituent material
Dynamic state	Behavior	Resemble each other on the functional performance
	Status	Resemble each other on the space-time state

Whereas, simply reacting to the current status of green building is not optimal. It is more important for staff to know when facilities will fail in the future and have enough time to deal with risks before they occur. Therefore, the second part of digital twin is prediction twin. Prediction twin refers to predicting the future state of physical entities based on a large number of historical data, existing state data or integrated network data learning (INDL) through establishing computing model, using machine learning, etc. INDL refers to the simultaneous operation of multiple physical entities of the same batch and feedback the data to the same information platform. And prediction twin will rapidly conduct deep learning and accurate simulation based on these massive data [7].

Control twin is depicted in Fig. 1. Specifically, the virtual model can be updated synchronously according to the actual state data of the physical entity. Meanwhile, the operation state of the physical entity can be adjusted through controlling the virtual model.

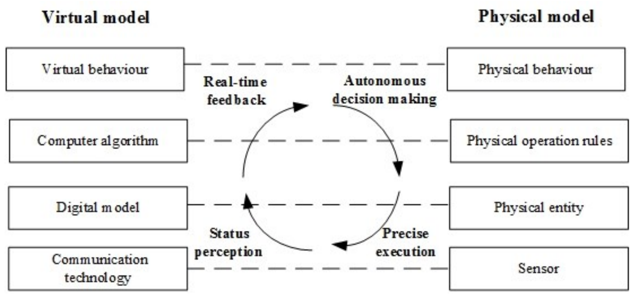

Fig. 1. The implementation method of control twin

B. Framework of the DT-GBMS

According to the characteristics and theoretical basis of GBMS, the framework of the DT-GBMS is shown in Fig. 2. The framework consists of four parts: status sensing layer, model collaboration layer, system decision layer and management control layer. And the driving force of the whole system is data.

Firstly, the status sensing layer is the lowest level of DT-GBMS, which is composed of various sensing nodes. This layer is responsible for collecting the status data of people, facilities, and environment, and preliminarily processing the data and uploading it to the corresponding database. It can also implement the control function according to instructions of upper layers. Secondly, the model collaboration layer is data-centric and responsible for the storage, searching, deployment, and management of data from both virtual and physical models. Its purpose is to compare the status differences between the virtual end and the physical entity and give real-time feedback to ensure the perfect mapping between them. Thirdly, the system decision level consists of various subsystems, which can call relevant data according to their own functions and conduct secondary processing on these data, so as to realize the control of green building. Fourthly, the management control layer is a collaborative management platform that can offer man-machine interaction functions and realize the communication management of all relevant parties. These participants can insert, extract, update, modify and view data according to their rights to support their collaborative work. In general, the proposed framework takes data as a bridge to organically integrate the above five functional layers, which establishes a data-driven green building maintenance system based on digital twin.

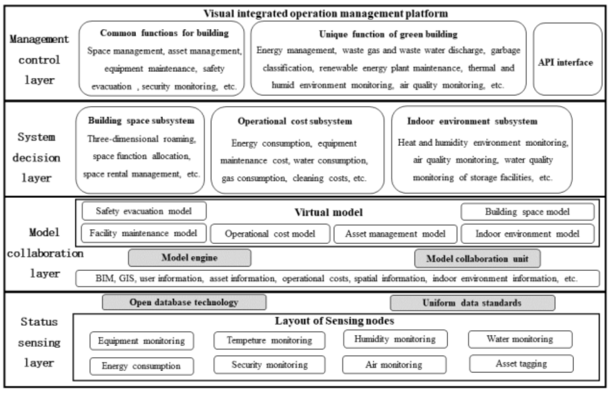

Fig. 2. The framework for DT-GBMS

C. Detailed design of the framework's functional layers

a. Status sensing layer

The state sensing layer is responsible for providing data reading and writing support to upper layers. On one hand, this layer can collect the real-time status data of building entities through sensing nodes, and realize the flow and storage of these multi-source heterogeneous data. That is, these data from different systems, formats and manufacturers are transformed into a public standardized data format and stored in specified databases. Meanwhile, the standard for data should have clear classification and coding rules, which can clarify the topological relationships between the components and form a hierarchical and reticular structure. On the other hand, this layer can control physical entities according to the instructions from upper layers.

The structure of sensing nodes proposed in this paper is depicted in Fig. 3. In order to make the system autonomous, the sensing node can conduct primary processing on certain data, making the controller output instructions to drive specific automatic equipment to adjust the operational status of the building entity. Namely, the whole process of "perception-computing-decision-execution" for a specific function can be independently completed.

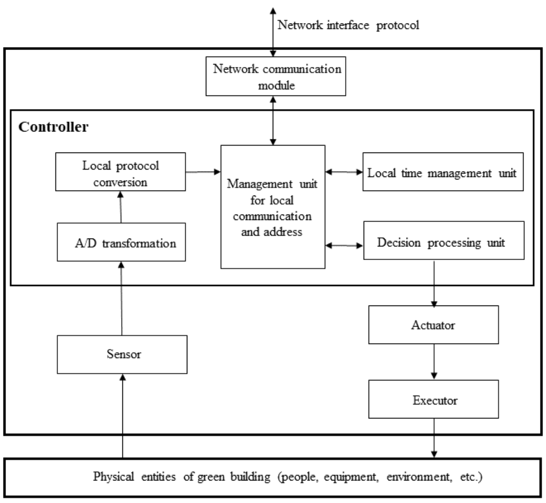

Fig. 3. The structure of sensing nodes

b. Model collaboration layer

The model collaboration layer is the core layer of DT-GBMS, which can provide a unified virtual model for upper layers to monitor physical entities by controlling the virtual model, and ensure the real-time mapping between the virtual and physical models. This layer is mainly composed of model engine and model collaboration unit, as indicated in Fig. 2. The model engine transforms various data of building entities into a unified virtual model, so that the system can realize corresponding functions according to the virtual model. The proposed model engine adopts an SOA structure, as shown in Fig. 4. The model collaboration unit periodically retrieves data from databases to compare the status differences between the virtual model and the physical entity, and give real-time feedbacks, so as to make them consistent.

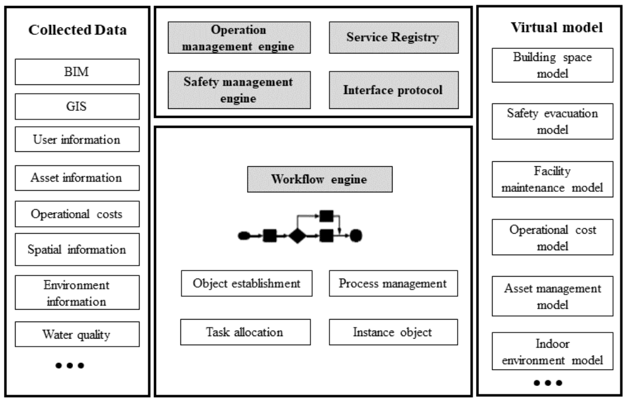

Fig. 4 The structure of model engine

c. System decision layer and management control layer

The system decision layer contains subsystems of various functions, which can call the relevant data from the model collaboration layer and output control instructions. For example, the asset management subsystem can realize the functions of asset information inquiry, asset inventory, etc.

The management control layer provides a visual management platform and API interfaces. Staff can carry out daily operational work on this platform according to their own authority. Meanwhile, the platform can communicate with the monitoring system of external departments through API interfaces, and offer the alarming linkage service.

D. Advantages of the DT-GBMS

The proposed DT-GBMS system can improve the informatization and automatic management of green components: (1) this system can provide a unified virtual model which maps to the green building by the proposed model engine and is capable of monitoring and controlling the complex and diverse green components. (2) it is a data-driven system, which can collect real-time status data of green components and give feedbacks through analyzing these accumulated data; (3) the designed sensing node has certain autonomy ability, which can independently complete the sensing and decision-making process for a specific function; (4) the proposed system adopts a public standardized data format, which can realize the flow and storage of multi-source heterogeneous data in the management of green building.

IV. PROTOTYPE FOR DT-GBMS

A. Development of the prototype

In this study, NavVis M6 mobile scanner is used to conduct 3D laser scanning of buildings and internal facilities, and then a virtual model is established in Bentley Systems software based on the generated point cloud data. NavVis M6 is an indoor mobile mapping machine that can automatically capture building's point clouds and 360° immersion images, as depicted in Fig. 5. Further, objects of the virtual model are categorized and integrated into the AssetWise platform to display data from environment sensors. AssetWise is Bentley's interconnected data environment to support asset lifecycle information management services. This prototype can make users navigate the virtual model and display status data by clicking on the objects, as indicated in Fig. 6.

Fig. 5. NavVis M6 mobile scanner

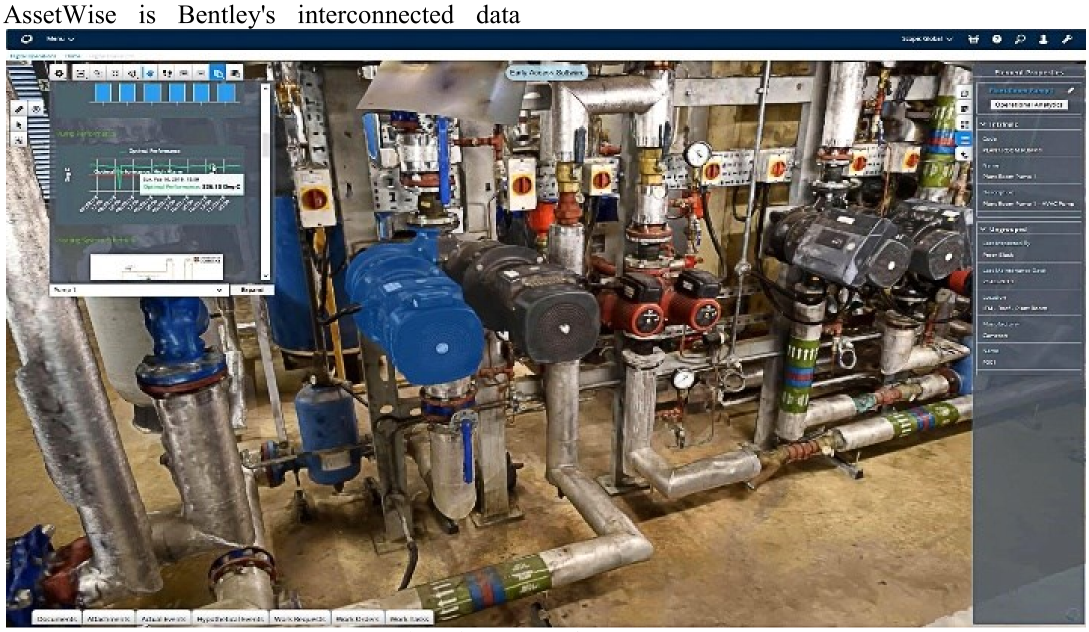

Fig.6 The prototype for DT-GBMS

B. Applications of the prototype

a. Asset management

This prototype can classify various objects in the model through creating asset registers and asset identification labels. Further, the barcode is placed on physical entities, the asset data of which is stored in the corresponding database. In practice, by scanning the barcode label, the staff can identify the facilities and query asset configuration files which can provide various descriptions of assets, as well as asset management data such as inspection time and inspection records. Meanwhile, the staff can also input information about assets according to their own authority, such as 'the refrigerator fails to work'. And this information will be timely notified to the manager.

b. Real-time monitoring of facilities

This prototype can collect real-time status data from green buildings by various sensors to monitor the operation of critical facilities and the internal environment. Nearly twenty sensors have been deployed so far, including temperature sensors, humidity sensors, etc. In practice, data from sensors can be transferred in real time to AssetWise platform to analyze facilities' operational index and predict potential failures. Meanwhile, the staff can also set security thresholds for facilities' operational indexes to monitor assets. If these indexes exceed predefined limits, an alert will be sent by E-mail or text.

V. CONCLUSION

The characteristics and theoretical basis of GBMS are analyzed in this study. Moreover, a DT-GBMS model has been put forward to solve the problem of insufficient informatization and automatic management ability of green buildings. In this model, the structure of the DT-GBMS is designed according to practical usage. Furthermore, the feasibility of the proposed model is validated with a prototype developed by 3D laser scanner and sensors. To recapitulate, the contributions of this model can be summarized as follows:

1) This study is one of the pioneers to apply digital twin technology to green building maintenance based on the characteristics of GBMS. The staff can directly manage the green buildings through the operation of DT-GBMS and the autonomous sensing node is also designed in the proposed model, which can effectively improve the automatic management capability of traditional GBMS.

2) The DT-GBMS proposed in this study is a data-driven model which can automatically collect and analyze the real-time status data of green buildings to ensure the perfect mapping between virtual model and physical entity and predict the possible faults of facilities. This model can solve the problem of large workload and poor timeliness of manual data collection in traditional building maintenance, so as to reflect the accurate and real-time information of green buildings and promote the timely physical response to changes.

3) The proposed model adopts standardized data standards and has specified classification and coding rules for information, which can improve the efficiency of reading and writing heterogeneous data from multiple sources and solve the problem of 'Data Island' faced by traditional GBMS.

Whereas, the implementation of the DT-GBMS is mainly faced with the following three obstacles:

1) *Data island*, namely, the data from different software and project stages cannot be well shared, relying on manual input or reconstruction. To solve this problem, on the one hand, the government needs to provide policy guidance. For example, Shanghai vigorously promotes the digital delivery of building drawings based on BIM. On the other hand, stakeholders should pay attention to the lifecycle management of the project and be oriented by the operational requirements of buildings. In the early stage of a project, the unified data standard for the delivery of the final results and the development task of the data interface should be agreed with all participants.

2) *The applicability of the proposed system*. For a new building, stakeholders can discuss how to meet the requirements of the development and application of the system at the beginning of a project. However, for existing green buildings, most of their drawings are stored in the form of CAD files, and it will take lots of manpower to establish digital models manually. Therefore, the prototype proposed in this paper adopts 3D laser scanner to build the virtual model, but it cannot generate the digital model of hidden facilities, such as pipelines behind a ceiling [8, 9]. At present, using image recognition technology to automatically generate 3D building models by scanning 2D drawings is one of the research hotspots [10, 11].

3) *Further improvements to the proposed system*. DT-GBMS involves the cross-application of multiple disciplines and is characterized by complexity, heterogeneity, autonomy and data-driven. The proposed prototype still needs improvements based on the business requirements of green building maintenance.

REFERENCES

[1] D. Z. Chen, W. S. Xu, Y. L. Yu and J. M. Tang, "Exploration of Smart Operation of Green and Healthy Building," construction technology, no. 08, pp. 28-30, 2018. (In Chinese)

[2] H.-P. Lin, C.-Y. Jung, T.-Y. Huang, H. Hendrick, and Z.-H. Wang, "NB-IoT Application on Decision Support System of Building Information Management," *Wireless Personal Communications,* 2020/04/27 2020.

[3] D. Minoli, K. Sohraby, and B. Occhiogrosso, "IoT Considerations, Requirements, and Architectures for Smart Buildings—Energy Optimization and Next-Generation Building Management Systems," *IEEE Internet of Things Journal,* vol. 4, no. 1, pp. 269-283, 2017.

[4] G. F. Xu, P. W. Xu, and Z. Wang, "Research on Data Sharing and Integration of Multi-source Information Systems," Beijing, China, 2015, p. 3.

[5] Y. Pan and L. Zhang, "Data-driven estimation of building energy consumption with multi-source heterogeneous data," *Applied Energy,* vol. 268, p. 114965, 2020/06/15/ 2020.

[6] C. Boje, A. Guerriero, S. Kubicki, and Y. Rezgui, "Towards a semantic Construction Digital Twin: Directions for future research," *Automation in Construction,* vol. 114, 2020.

[7] S. Balachandar and R. Chinnaiyan, "Reliable Digital Twin for Connected Footballer," in *International Conference on Computer Networks and Communication Technologies*, Singapore, S. Smys, R. Bestak, J. I.-Z. Chen, and I. Kotuliak, Eds., 2019// 2019: Springer Singapore, pp. 185-191.

[8] A. Bhatla, S. Y. Choe, O. Fierro, and F. Leite, "Evaluation of accuracy of as-built 3D modeling from photos taken by handheld digital cameras," *Automation in Construction,* vol. 28, pp. 116-127, 2012/12/01/ 2012.

[9] H. Fathi, F. Dai, and M. Lourakis, "Automated as-built 3D reconstruction of civil infrastructure using computer vision: Achievements, opportunities, and challenges," *Advanced Engineering Informatics,* vol. 29, no. 2, pp. 149-161, 2015/04/01/ 2015.

[10] L. Gimenez, S. Robert, F. Suard, and K. Zreik, "Automatic reconstruction of 3D building models from scanned 2D floor plans," *Automation in Construction,* vol. 63, pp. 48-56, 2016/03/01/ 2016.

[11] C. Riedinger, M. Jordan, and H. Tabia, "3D models over the centuries: From old floor plans to 3D representation," in *2014 International Conference on 3D Imaging (IC3D)*, 9-10 Dec. 2014 2014, pp. 1-8.