Digital Twin-based Smart Building Management and Control Framework

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Abstract. Digital Twin is a digitalization technology that combines various technologies such as cloud computing, Internet of Things, and big data to implement interaction between physical and virtual spaces. This article describes the application of digital-Twin in the field of building and proposes a digital twin-based intelligent building management framework to achieve a more proactive, efficient, convenient and environment-friendly management control method throughout the life cycle. Finally, three application scenarios are listed under the digital twin-based smart building framework.

Introduction

Buildings are special industrial products whose value is reflected in the long-term operation process. Today, when information and communication technologies are fully infiltrated into society, there is an unprecedented breakthrough in the relationship between building, technology and people. Liu Chang et al. [1] proposed the concept of smart building, that is, “buildings and people, network, application, service system tightly coupled, complex system with integrated intelligence capabilities such as perception, memory, judgment and decision-making”, which highly summarizes future imagination and expectation of building development.

Referring to a new management model called “proactive manufacturing” based on the degree of big data utilization in manufacturing industry, the building evolution of life cycle management will also go through these four phases: passive, real-time, predictive and proactive (Figure 1), namely from a passively responds to householders’ demands and give corresponding feedback to predicting the behavior and state of facility and human resources proactively.

![Figure 1. The evolution of Building Management and control strategies.](image)

On the final proactive stage our aim is to create a more efficient, economical and household-friendly environment. Therefore, how to implement proactive management and control is one of the key issues that the construction and housing industry faces. Only on this basis can smart buildings enter the stage of intelligence and finally reach the level of smart management and control.
Digital Twin – A Data Model that Runs through all Phases of the Building's Life Cycle

The concept of Digital Twin was first introduced by Professor Grieves in 2003 [1]. Later, the US Department of Defense introduced the concept of digital twin into the maintenance of spacecraft and defined it as a multi-physical, multi-scale, multi-probability simulation process, based on the physical model of the aircraft to construct its complete mapping. Digital twin has the following characteristics [3]:

- integrating various types of data of physical objects, is a faithful mapping of physical objects;
- exists in the entire life cycle, evolving with it, and accumulating relevant knowledge;
- can not only describe physical objects, but can be optimize them based on models.

Digital twin-related technology has been applied and validated in industrial fields. In 2011, Tuegel et al. [6] sought to establish an ultra-high fidelity digital twin simulation model to accurately predict the life and damage of a spacecraft structure. Grieves [7] studied methods of fault prediction and elimination in 2017 based on digital twin technology and then applied it in NASA related systems. In addition, companies such as PTC and Siemens have also proposed digital-twin related products and business solution.

The application of information technology in the housing and construction industry is Building Information Modeling (BIM) which is a digital representation of physical and functional characteristics of a facility [4]. Difference between BIM and Digital Twin is that, digital twin technology emphasizes the connection between virtual and reality, and the co-evolution with physical objects, while BIM is an information management platform which lack of the application in the Internet of Things. BIM is foundation of digital twin technology applied in building industry and make it easier to realize this concept.

Framework of Digital-Twin Based Smart Building

![Diagram of Digital-Twin Based Smart Building Management and Control](image)

Figure 2. Framework of digital-twin based smart building management and control.
Digital twin technology is considered to be a key technology for implementing network physical systems (CPS). In this paper, we present a framework for digital-twin based smart building management and control methods. Four core components are detailed in the framework (shown in Figure 2) as follows:

Physical Building, Real-Time Obtaining, Organization, and Management of Data

The building physical space is mainly responsible for accepting the tasks assigned by the digital-twin system and pre-defining the instructions according to the virtual building model to complete the relevant control actions. However, unlike the conventional buildings, the physical space under the digital-twin system needs to have real-time physical data, such as the indoor temperature of the temperature control system, the cooling water and the chilled water temperature, and real-time video monitoring data. IoT technology can be applied to multiple subsystems of the building to ensure the timeliness and accuracy of building data effectively.

In addition, the digital-twin concept provides a new solution for buildings’ data management. Buildings’ digital twins act as a single source of data throughout their life cycle. It enables suppliers to collaborate in facility selection, design planning, facility utility and maintenance.

Virtual Building, Construction of Smart Building Digital Twin Model

Virtual buildings are essentially a collection of models [1], which consider three levels: elements, behaviors, and rules. At the element level, the virtual building models are very complete. To mapping physical space through digital modeling techniques, commonly used tools are AutoCAD, Sketchup etc. Methods such as finite element method (FEM) and boundary element method (BEM) can be used to simulate the physical function and performance of an element. In terms of behavior, virtual twin consists of elements of behavior and their response mechanisms, including human actions, facility operations, and virtualized models of material transportation. In terms of rules, it mainly includes rule
models such as assessment, optimization, prediction, and traceability based on the numerous operational and evolution laws of the workshop. Edging algorithm methods such as data analysis, machine learning, and knowledge mining are indispensable.

**Building Data Organization and Management**

Building data presents the typical “3V” characteristics of big data [5], namely volume, variety and velocity. It is necessary to build a large-scale data storage and management platform to lay a solid foundation for digital twin. The data from building digital twin systems includes not only physical space data, but also data related to buildings in virtual spaces. The latter consists of model data and operations that compose data for digital twins, such as simulation data, prediction data, and evaluation data. The Big Data Storage and Management Platform serves as a single data source for data support for physical buildings, building digital twins, and building operations service platforms. It is the motivation and foundation for smart building management and control systems.

**Smart Building Service Platform, Digital-Twin Based Smart Building Management and Services, and Big-Data Driven Prediction**

The Building Operations Service platform as shown in Figure 4 refers to a collection of technologies that support the functional and target requirements of smart building management and control. It includes monitoring, forecasting and optimal control of building energy, internal resources and facility management. It consists of a predictive service platform and an operational management and control service platform. This Platform is a prerequisite for predictive management and control, providing forward-looking information for operational management and service platforms.

![Figure 4. Digital twin-based building management service and prediction framework [9].](image-url)
of optimal decision-making is transformed from a causal relationship analysis model into a correlation analysis model. This provides a new approach to building environment optimization and operational decision making, especially for large-scale resource allocation and optimization issues.

Conclusion

Although the concept of smart building has long entered the sight of real estate developer operators, the current building informatization mainly focuses on data collection, comprehensive analysis and visualization, while ignoring informatization and building management itself, and lacking the entire building simulation prediction of the whole life cycle. Through dynamic simulation and other technical methods, real-time online management based on digital twin technology concentrates on people and objects in the building and collecting data, and obtaining operational information that cannot be directly collected through simulation calculation from the collected data, which can be used for early prediction and automatic repair and operational services to enhance building intelligence, health and economic level. It realizes the digitalization of buildings, predicts construction problems, plans construction operation measures, and improves the life cycle of information solutions for building development.

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