Kalpa Publications in Computing
Volume 22, 2025, Pages 720–731
Proceedings of The Sixth International Conference on Civil and Building Engineering Informatics

Streamlining Sensor Registration and Updating Process in BIM-Based Digital Twin

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Abstract

In response to the global climate crisis, managing building energy usage to achieve energy efficiency and low carbon emissions is becoming increasingly important. With the help of Digital Twin technology, building energy data can be collected, analyzed, and simulated for more efficient building operations. However, sensor registration and updating still lack an integrated process, resulting in ineffective collaboration between equipment providers and building managers, and further data maintenance issues. To address this situation, we propose a streamlined collaboration and management platform, realized through the Application Programming Interfaces (APIs) of Autodesk Platform Services (APS) and Building Information Modeling (BIM). This platform aims to integrate the complex processes of constructing digital twins, including sensor registration, spatial coordinate management, energy data collection, and updates. At the same time, a streamlined user interface is designed to enable a cohesive and integrated workflow, facilitating data updates and maintenance for building managers in the future and reducing the difficulty of developing and maintaining digital twins.

1 Introduction

The application of digital twin technology in the construction sector is advancing rapidly, particularly in enhancing the energy efficiency of existing buildings. Compared to traditional methods, digital twin technology can optimize energy use through real-time data monitoring and simulation, which is crucial for transforming existing buildings into "Net Zero Energy Buildings (NZEB)" (Kaewunruen et al., 2018). However, the deployment of digital twin technology faces several challenges.

First, the high initial capital investment is a major barrier, especially for small and medium-sized building owners, due to the high cost of integrating Internet of Things (IoT) devices, sensors, and data processing systems (Cespedes-Cubides & Jradi, 2024). Additionally, the complexity of digital twin systems requires skilled personnel and management teams, which increases the need for training and infrastructure upgrades, making the deployment process more complicated and lengthy. Another challenge is the inefficient management of historical energy data and digital models. Differences in data storage methods often lead to difficulties in updating and managing data, reducing the effectiveness of digital twin technology. Addressing these issues is, therefore, crucial.

Building on the framework proposed by (Lee et al., 2019), which integrates government open data with sensor data for smart construction site management, this research further developed an integrated workflow for registering, managing, and viewing building information and sensor data. This research also referred to the model management interface proposed by (Nagy, 2017) to establish a visual platform to support this workflow. This approach emphasizes data integration and enhances the connection between BIM and IoT, resulting in broader data management capabilities and improved scalability. These improvements simplify the implementation and maintenance of digital twins, ultimately enhancing building projects' management efficiency.

In addition, this workflow simplifies the implementation and maintenance of digital twins, allowing users to utilize the platform for data visualization and other technologies without requiring prior experience in BIM modeling or software operation. It enhances the management efficiency and applicability of construction projects.

2 Method

2.1 System Design for Integrated BIM and IoT Data Management

The system architecture follows a typical three-tier structure, consisting of the Application Layer, Business Layer, and Data Layer, moving from the user interface to the core data management functions. Each layer contains specific functional modules to support the integrated management of Building Information Modeling (BIM) and Internet of Things (IoT) sensor data. The application can be divided into three types of data access, corresponding to different users and their interactions with Building Information Modeling (BIM) models and Internet of Things (IoT) data, as shown in Figure 1. The first type is Building Model Management, where building managers can manage all data on the platform, including creating model projects, updating model versions, editing sensor information, and issuing authorization codes. The second type involves Sensor Registration, where sensor registrants can upload sensor data to the model and link real-time or historical data to the corresponding data tables. The third type is the Visualization of Models and Sensor Data, allowing general users to view building models and real-time sensor data through the platform. This workflow supports the realization of digital twins (DT) for buildings and reduces the complexity of data maintenance.System Design for Integrated BIM and IoT Data Management.

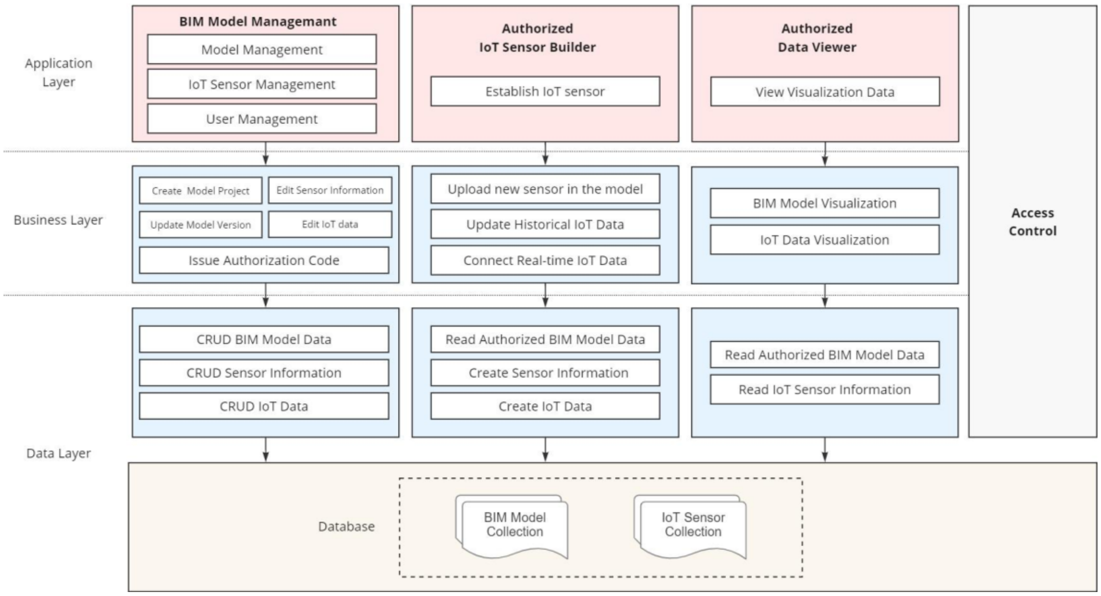


Figure 1: The three-tier diagram of the proposed platform

2.2 Database Design in the System

Regarding the storage method for BIM models and IoT data, instead of directly embedding sensor components within the BIM model and storing data there, the data is independently stored in a separate database, as shown in Figure 2. Different versions of BIM models are recorded in the project table, allowing efficient model version control, while sensor data is linked to individual projects. This method facilitates the independent management of models and sensor data, ensuring the accuracy of the most up-to-date model and sensor information. Additionally, this approach helps maintain system scalability and ease of maintenance.

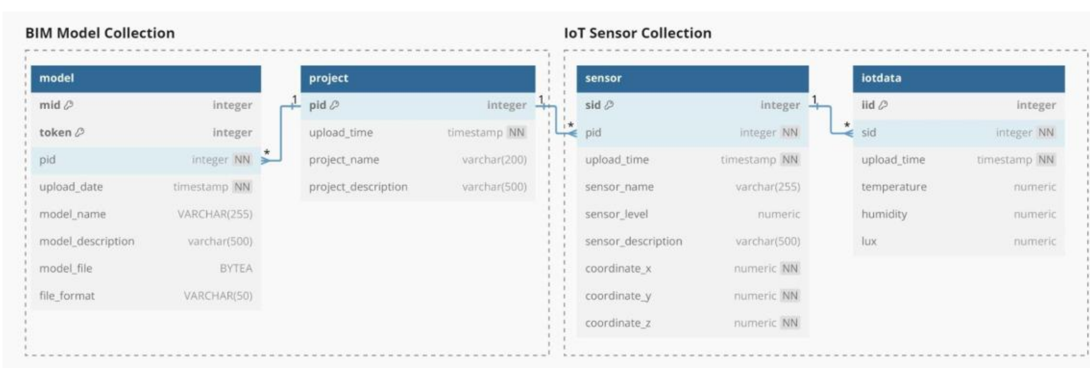


Figure 2: The database diagram for the proposed workflow

2.3 Collaboration Workflow in the Platform

The workflow for data management, sensor registration, and data visualization is illustrated in Figure 3. First, the data manager needs to log in and either create a new project or update the model version of an existing project. If a new project is selected, the system will create a new sensor database for the project. If an existing project requires an update, the latest BIM model will be uploaded and updated in the model database to allow sensor registrant later in the project. Next, the sensor registrant must enter an authorization code to access the previously uploaded and authorized model by the data manager. The uploading of sensor data takes place in two steps: first, establishing the sensor's coordination and description within the model in a 3D environment and then uploading and linking the sensor data, thus allowing the BIM model and IoT data in the project to be interconnected. Finally, data viewers can use the platform to select models that are open for viewing by the data manager. This allows them to view the building model and its real-time sensor data, providing a better understanding of building operations and energy management. Overall, the platform offers an integrated workflow from model management to sensor setup and data visualization, reducing the complexity of digital twin implementation and data maintenance.

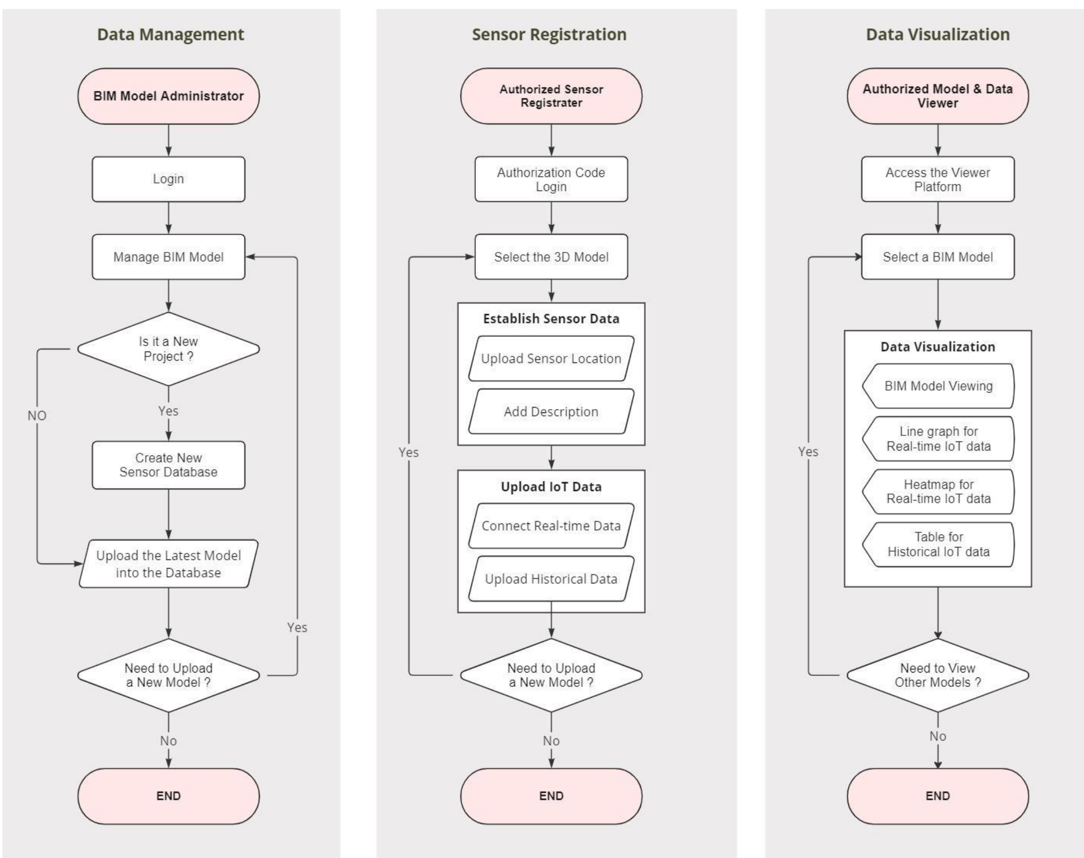


Figure 3: The flowchart in the proposed platform

3 Result & Discussion: A Case Study

This paper uses the Civil Engineering Research Building at National Taiwan University as a demonstration model, with sensors installed in Room 611 on the sixth floor to demonstrate the workflow described above. Figure 4 shows the platform's user interface, which is explained in three parts: (1) the building administrator uploading and managing the building model, (2) sensor data uploading by the sensor registrant, and (3) model data visualization for general users.

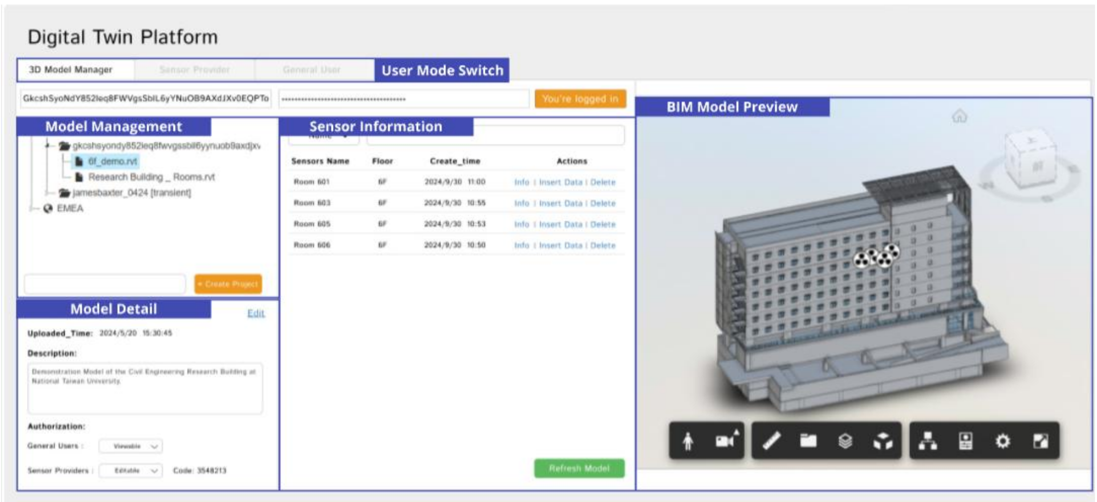


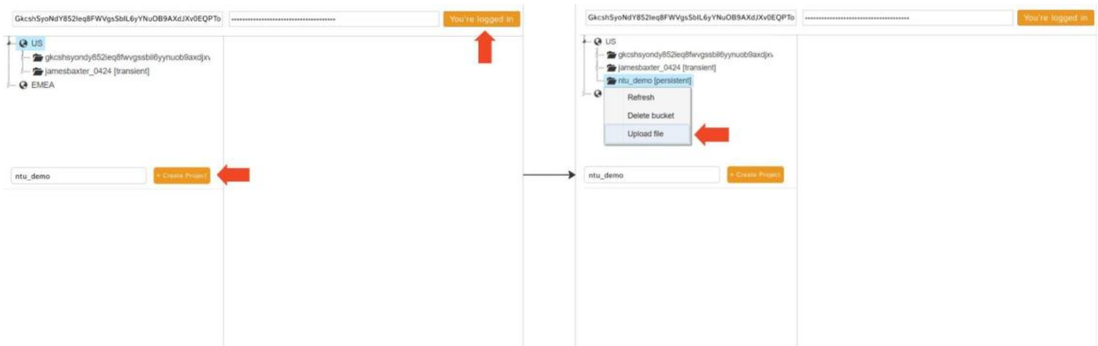
Figure 4: The user interface in the proposed platform

3.1 BIM Model Administrator

BIM Model managers can perform the following operations on the platform: (1) Model Upload and Management: Administrators can upload and manage multiple building models. (2) Sensor and IoT Data Management: Administrators can handle sensor data associated with the uploaded models.

3.1.1 Upload and Management

First, the data manager must log in to the management system using their account. After selecting the regional server, they can browse all projects associated with their management account. As shown in Figure 5, to create a new project, the manager can use the 'Create new project' button and enter the project name to establish a new project. To upload a model, right-click on a specific project to upload a BIM model. Within each project, models are displayed in the order they were uploaded, facilitating efficient management of different versions. Finally, detailed information is displayed on the interface by clicking on a specific model, including model information, permission settings, BIM model preview, and a view of all IoT sensors within the model, as illustrated in Figure 6.



(a) Log in and select a server to create new project (b) Select a project to upload model

Figure 5: The Key steps for creating projects and uploading model

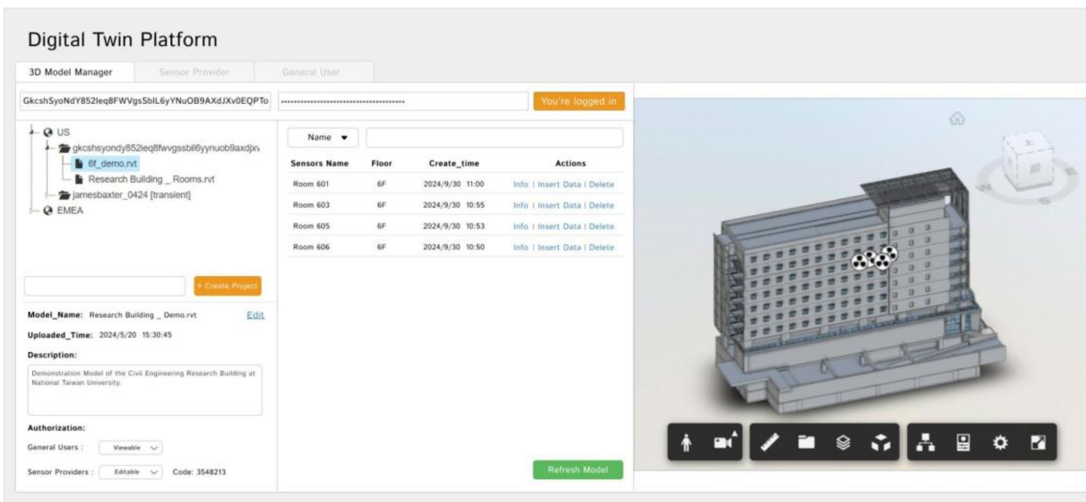
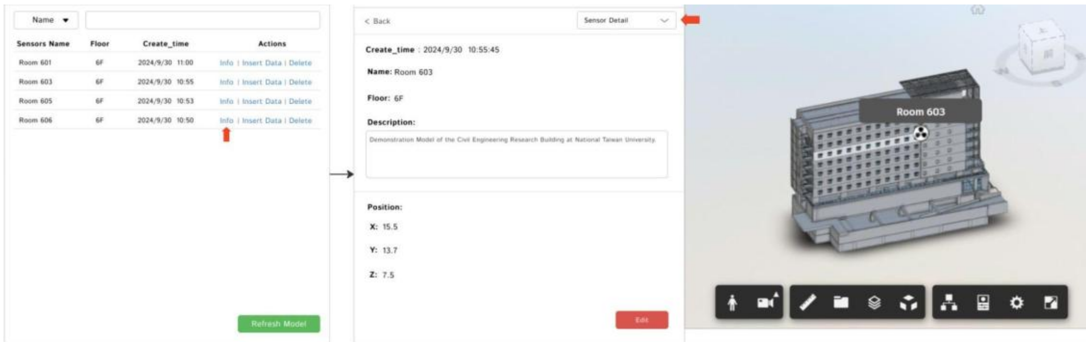


Figure 6: The user interface for the data manager

3.1.2 Sensors and IoT Data Management

As shown in Figure 7, to manage and view IoT data, users can click on a specific sensor's "info" button in the platform. The sensor information will be synchronized and displayed in the BIM model viewer on the right side. Using the dropdown menu, users can edit the sensor's spatial coordinates within the model, modify historical sensor data, and check the status of real-time data reception, as illustrated in Figures 8 and 9.



(a) Click "info" to acess sensor detail

(b) Detail information and sensor preview in the model

Figure 7: Key steps for viewing sensor detail information

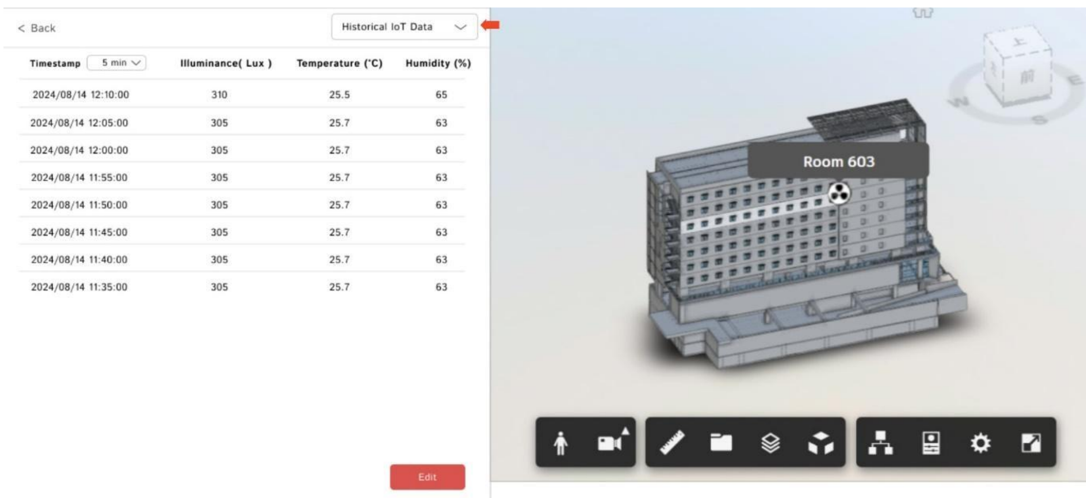


Figure 8: Historical IoT data viewing

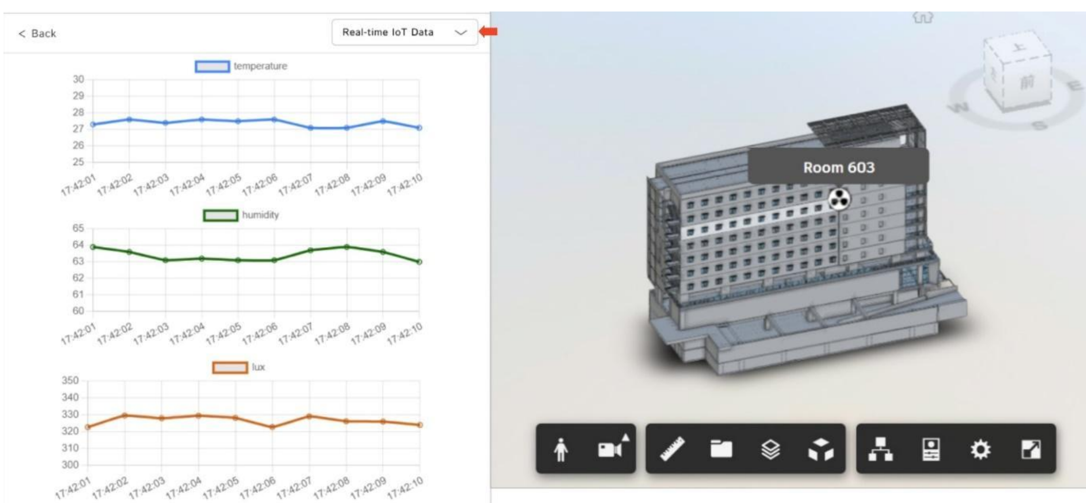


Figure 9: Real-time IoT data viewing

3.2 Sensor Registration

The sensor registrar can perform the following operations on the platform: (1) Place the new sensors in the model: set up and define the spatial coordinates for new sensors within the model. (2) Input historical and real-time sensor data: integrate historical sensor and real-time data into the database.

This registration method facilitates the quick and simple addition of sensor locations and data reception. Even without a basic understanding of BIM models or modeling software technologies, the general public can easily use this platform to set up sensor components and visualize information, promoting the adoption of Digital Twin technology. Moreover, since sensor and model data are stored separately, updates or adjustments to room names and interior spaces within a Revit model do not directly affect the sensor storage state. This approach enhances the convenience of separately maintaining model and sensor data during internal collaboration. It prevents issues such as version conflicts if both types of data are stored in the same Revit file and updated simultaneously by different users.

3.2.1 Place New Sensors in The Model

The placement of sensors will be completed in several steps. First, as shown in Figure 10, users must enter an authorization code to access the model authorized by the data manager. At this stage, any previously established sensor information and the model can be viewed through the interface. Users can begin the sensor placing process after clicking the 'Create new Sensor' button. As shown in Figure 11, the placement of sensors involves several steps. After switching the model floor, users can click the 'Get Coordinates' button and click on the model to obtain the coordinates within the model in a 3D environment.

Additionally, after clicking, a sphere will be created at the selected location in the model. Users can then use the transform controller to adjust the sphere, fine-tuning the desired coordinate position. Finally, the newly added sensor can be previewed in the model by pressing the' Save' button.

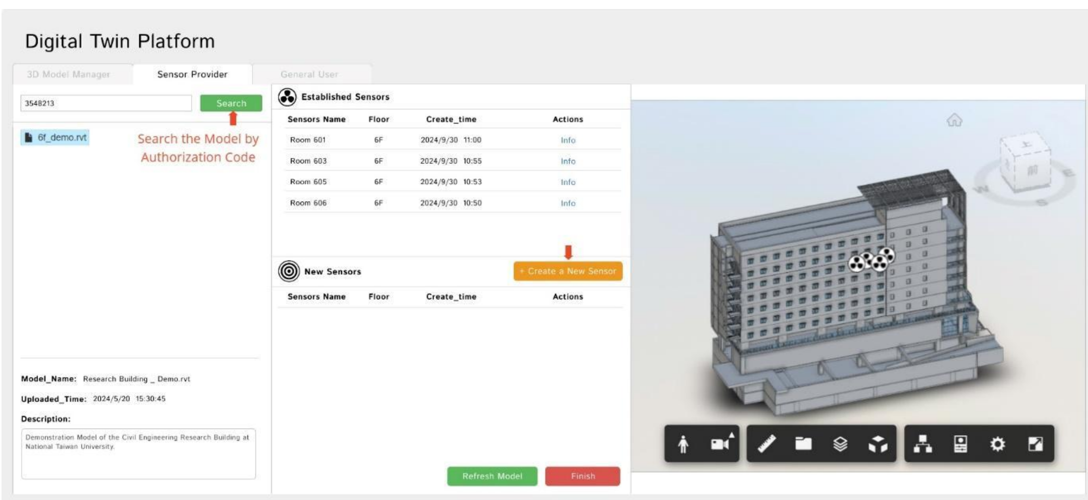


Figure 10: The user interface for sensor registration

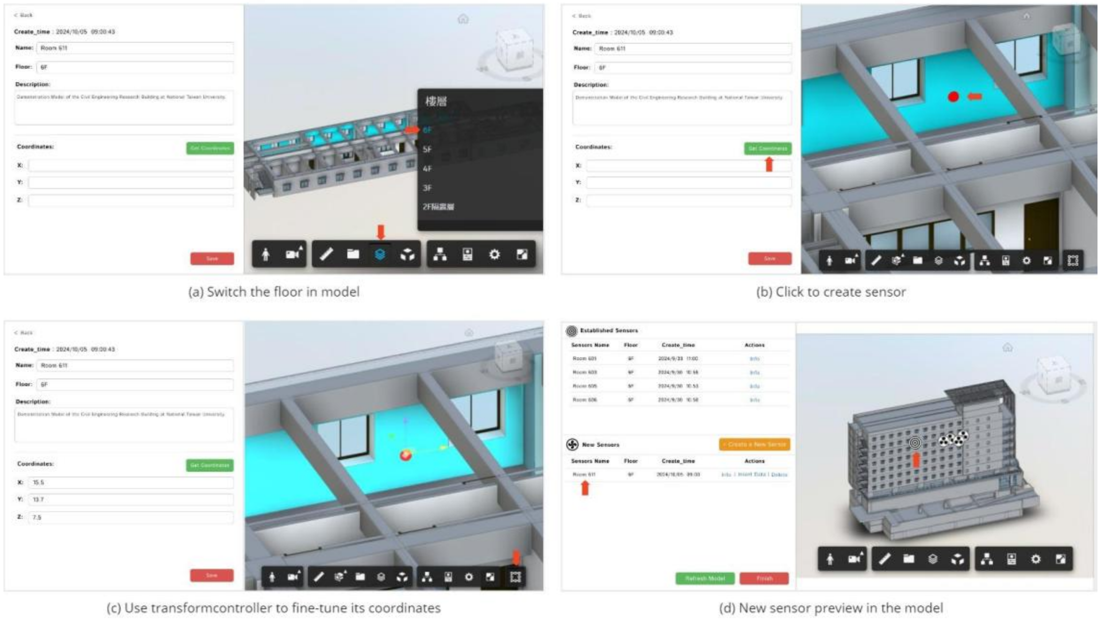


Figure 11: Key steps for registering a new sensor

3.2.2 Upload Historical and Real-time Sensor Data

After placing a new sensor in the model, as shown in Figure 12, users can click to insert data into the sensor and switch to IoT data input via a dropdown menu. In this study, it is expected that all data collected by the sensors will first be transmitted to a database, from which the platform retrieves and displays the data. To facilitate real-time data collection from sensors, an API is provided for sensors to upload real-time data to the database, which the platform can then access and display. For sensors that have already collected data that needs to be integrated into this platform, an option to upload CSV files is provided to import the data into the database. Combining new and historical data through these two methods enables efficient data searching and viewing.

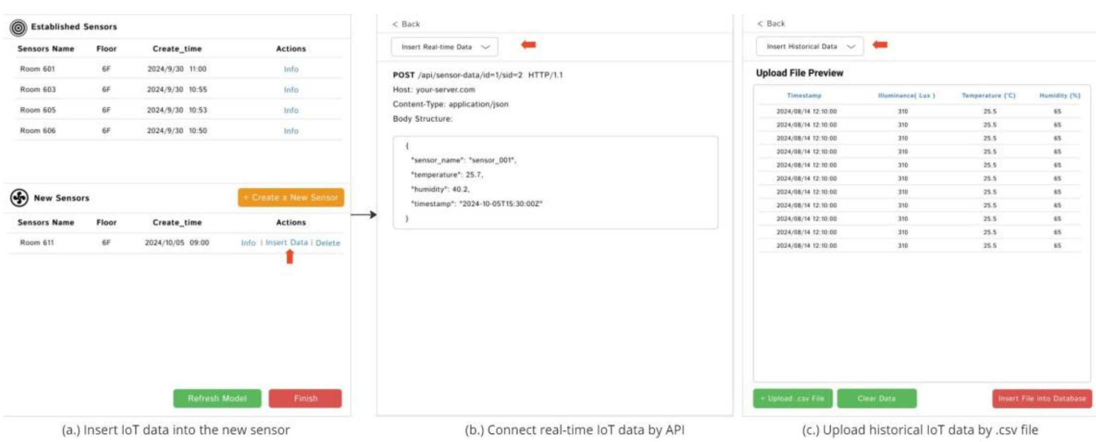


Figure 12: Key steps for uploading IoT sensor data

3.3 General User

As shown in Figure 13, a dropdown menu allows general users to view the models authorized by the manager. This includes accessing and analyzing historical energy data and viewing real-time sensor data from different spaces within the building through various visual representations, such as thermal maps, icons, and line charts, as depicted in Figures 14 and 15. This functionality helps users comprehensively understand the energy dynamics within the building.

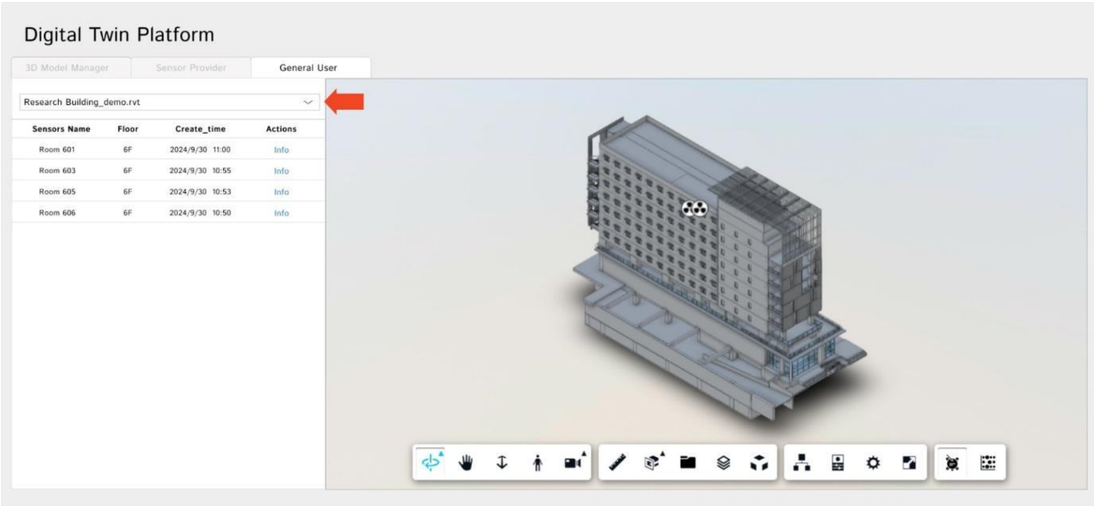


Figure 13: The user interface for general user

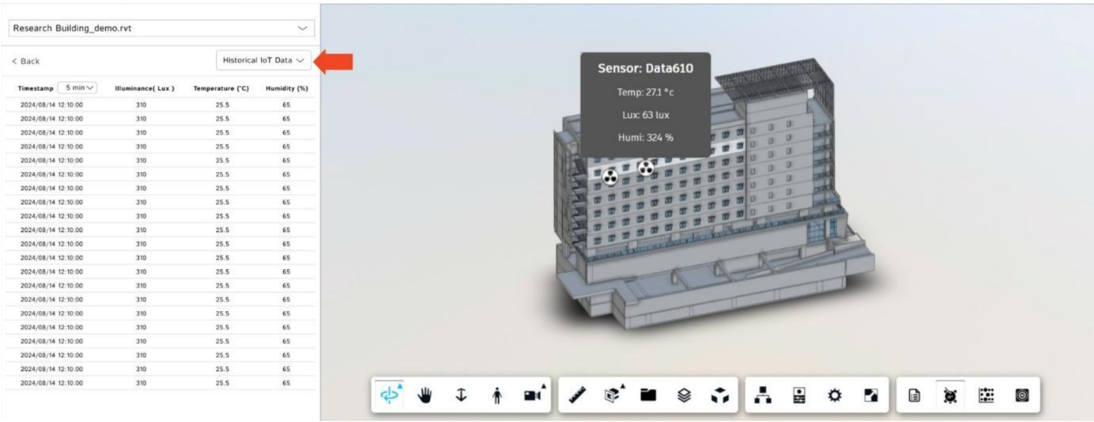


Figure 14: Historical IoT data viewing

Figure 15: Historical IoT data viewing

3.4 Limitations

The workflow and methods for storing model data and sensor data mentioned in the article still need to be solved. One major issue lies in the accuracy of sensor coordinates. After installing sensors on-site, registering their coordinates on the platform is relatively simple, often leading to imprecise coordinate information. Additionally, their coordinates must be manually updated on the platform when repositioning sensors.

Another challenge arises when significant updates occur in the model space. The current data storage approach is designed to accommodate minor adjustments, such as the removal of partition walls, updates to equipment information, or reconfigurations of indoor spaces. However, sensor coordinates are recorded as absolute positions within the model space. Suppose the building model undergoes significant shifts (e.g., a large-scale repositioning of the entire structure within the model space). In that case, the sensor coordinates may become misaligned, requiring manual updates to restore visualization functionality.

Finally, the system displays the latest model version and the most recent sensor positions. However, it needs to effectively record and manage historical data, including earlier model versions and past sensor information. This limitation poses challenges for tracking changes over time and ensuring data consistency across different versions.

4 Conclusions & Future Work

This study streamlines the complex process of building a digital twin, achieving an integrated workflow through establishing a platform. Data storage is divided by purpose into model and sensor data storage, ensuring efficient and organized data management. The platform's integrated workflow meets the needs of three main types of users, each with specific workflows for effective data management and system utilization. Moreover, the framework facilitates efficient data management and maintenance by storing model and sensor data separately. In addition, through a user-friendly sensor registration method, the framework enables individuals without knowledge of BIM modeling or software operation to access digital twin technologies and visualize data. This streamlined approach aims to foster a more cohesive and integrated process, ultimately reducing the complexity and cost of implementing and maintaining the digital twin.

In terms of future development, the study's primary objective is to establish a digital twin platform for the National Taiwan University campus. Through data visualization and environmental simulation, this platform aims to assist the university in addressing key issues, such as understanding the relationship between occupancy and energy consumption or the impact of environmental temperature and humidity on space energy efficiency. The platform will enable university management to make informed decisions. However, challenges arise during communication between campus administrators and academic departments, as some staff may need more technical background to operate complex systems. The simplified workflow proposed in this study addresses these challenges by establishing a clear system framework, categorized into three user types—administrators, data uploaders, and data viewers—to implement the platform and ultimately fulfill its goal of supporting campus management and decision-making through digital twin technology. Although the security of sensor data collection is not the primary focus of this research, it will be one of the key aspects to address in the future development of the proposed framework

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