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Research Article

An Information Integration Platform for Visualizing Campus Sustainability with Digital Twin—A Case Study of National Taiwan University

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Abstract

Universities are increasingly expected to demonstrate social responsibility and reduce environmental impacts as part of their commitment to sustainable development. However, the complexity and diversity of campus facilities and stakeholders make managing sustainability initiatives a significant challenge. Digital dashboards have emerged as effective tools for monitoring environmental performance, identifying issues, and enhancing communication among stakeholders. Despite their potential, the development and implementation of such dashboards are often hampered by fragmented data collection, integration, and management across various administrative units and user groups.

This study addresses these challenges by proposing a robust system framework designed to streamline data management and support the visualization of campus sustainability efforts. Using National Taiwan University as a case study, we developed an information integration platform capable of organizing, integrating, and managing a wide range of general and environmental data types from multiple sources. The platform's multi-level data structure and user management modules enable tailored access and visualization for different stakeholders, strengthening data governance and fostering a culture of information sharing. Ultimately, the proposed framework contributes to a more sustainable and transparent campus environment, supporting strategic decision-making and advancing the university's sustainability goals.

Keywords: Smart Campus, Information Management System, Data Integration, Digital Dashboards, Environmental Performance Monitoring

Highlights

- Developed a platform to integrate and visualize diverse campus sustainability data.
- Implemented a multi-level data structure supporting 1D, 2D, 2.5D, and 3D data types.
- Enabled tailored data access and visualization for multiple university stakeholder groups.
- Strengthened data governance and transparency to support campus sustainability goals.

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1 Introduction

Universities worldwide are increasingly required to demonstrate social responsibility and reduce their environmental impacts as part of their commitment to sustainable development. As institutions that shape future leaders, innovators, and policymakers, higher education institutions (HEIs) play a pivotal role in addressing global sustainability challenges (Lozano et al., 2013). Nevertheless, managing sustainability efforts is challenging due to university campuses' diverse facilities and occupants, as well as competing priorities like financial constraints and infrastructure limitations (Ávila et al., 2017). These challenges underscore the need for innovative solutions that can streamline sustainability practices and foster accountability.

Digital dashboards have emerged as a valuable tool for tracking environmental performance, identifying critical issues, and improving decision-making processes (Yigitbasioglu & Velcu, 2012). These systems enable universities to monitor their progress toward sustainability objectives while fostering transparency and collaboration among stakeholders (Ceulemans et al., 2015, Bice & Coates, 2016). Despite their potential, the development and implementation of such dashboards are frequently hindered by challenges related to data collection, integration, and management across administrative offices and user groups (Berzosa et al., 2017).

Recent advancements in digital twin technology provide promising solutions to these challenges. For instance, Chen et al. (2023) developed a digital twin platform based on 3D building models and smart IoT sensors for visualizing campus environmental data in real-time. This platform integrates static and dynamic information within a WebGIS interface to support decision-making processes for climate-resilient campus development. Similarly, Chang et al. (2024) utilized Building Information Modeling (BIM) to construct digital twins for university buildings, emphasizing energy efficiency, indoor environmental quality, and material circularity. Their study demonstrated how smart sensors linked with BIM models can create dynamic dashboards for monitoring campus sustainability indicators. Building upon these advancements,

This study addresses these challenges by proposing a robust system framework designed to streamline data management practices and enhance information sharing within university campuses. Using National Taiwan University as a case study, this research develops an information integration platform capable of organizing, integrating, and managing diverse environmental data types sourced from multiple providers, including administrative offices, facilities management teams, and external sustainability partners. The framework also caters to various user groups such as university decision-makers, researchers, students, and campus operations staff, enabling them to access tailored visualizations for informed decision-making. By accommodating different types of data—ranging from energy consumption and water usage to waste management and greenhouse gas emissions—the proposed framework strengthens data governance policies and fosters a culture of information sharing. Ultimately, it contributes to creating a more sustainable and transparent campus environment while supporting strategic sustainability goals.

2 Methodology

Our system design was based on its functionality, information and data level, along with user and data management. More detailed information is provided in the following subsections.

2.1 System Framework

Our campus information integration platform is composed of four key modules (as shown in Figure 1): (1) data processing: including layers such as data acquistion, integration, display and publishing, (2) data management: including functions such as data approval, deletion and publishing, (3) user management: including functions such as account registration, approval, deletion, and (4) notification: including functions such as notifying account and data status, data request.

As showin in Figure 1, the data processing module is our system's core, composed of four main layers: (1) data acquisition: storing different types of data from different sources, including tables, maps and models, (2) data integration: creating new projects, linking new data with old one in existing projects, (3) data display: displaying data by different information and data levels (see subsection 2.2) with different types of viewers (e.g., ArcGIS 2D and 3D viewer, APS model viewer), and (4) data publishing: publishing data onto various cloud services for further visualization work (e.g., PowerBI, ArcGIS cloud).

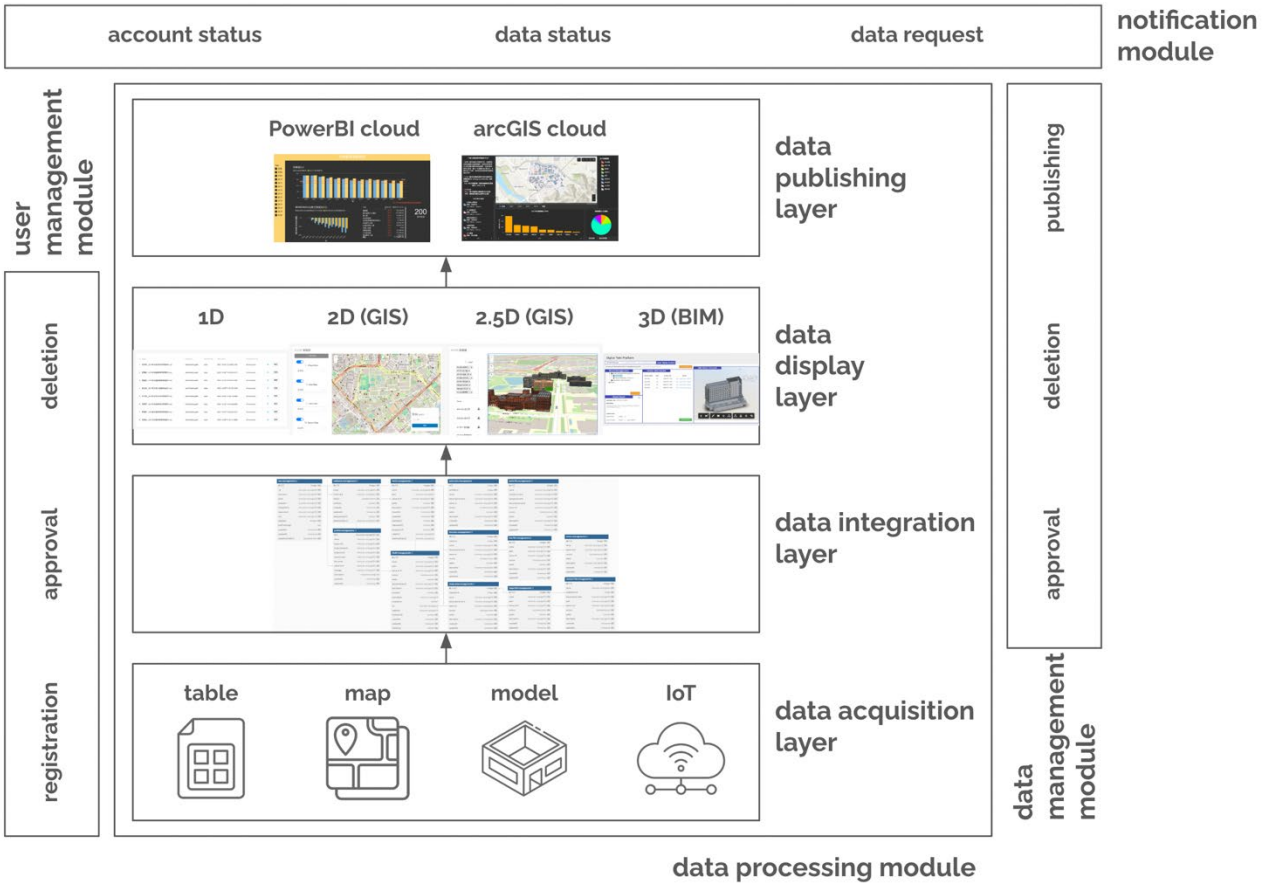

Figure 1. System framework of our campus information integration platform

2.2 Information and Data Level

Since a university campus is a vast entity composed of various buildings and facilities, different levels of information are essential to understand its past, current and potential sustainability performances in a comprehensive yet thorough manner, fostering informed decision making for advancing sustainability. For instance, to understand whether the university has achieved its overall building energy consumption saving goal, its total annual building energy consumptions throughout the years should be obtained, analyzed and visualized. Afterwards, to understand and compare the energy performances of different

buildings on the campus, the individual annual/ monthly/ daily building energy consumptions are vital. Furthermore, to understand and compare the energy demands and performances of different rooms in a building, their daily/ hourly/ daily building energy consumptions and occupancy are critical.

Corresponding to different levels of information required, this study proposed four data level framework for our campus information integration platform as shown in Table 1. 1D data refers to dataset without spatial information, while 2D data refers to 2D maps, 2.5D data refers to 3D maps and 3D data refers to 3D models. Their data types and display methods are file-based, GIS-based, and BIM-based separately. And the display levels vary from campus, building and room level.

Table 1. Information, data, and display levels in our campus information integration platform

Information level	Overall ⟷ Detailed			
Information example	Total annual building energy consumptions by campus	Annual/ monthly/ daily building energy consumptions by building		Daily/ hourly building energy consumptions by room
Data level	1D Data (without spatial info)	2D Data (with 2D spatial info)	2.5D Data (with 2.5D spatial info)	3D Data (with 3D spatial info)
Data type	File-Based	GIS-Based		BIM-Based
Data example	Table (e.g., csv)	Map (e.g., shp)	Map (e.g., shp)	Model (e.g., rvt)
Display level				
Campus	(v)	v	v	x
Building	x	(v)	v	v
Room	x	x	(v)	v

2.3 User and Data Management

Besides system adminstrators, we categorized the main users of our system into two types as shown in Table 2: the division and individual. The former one is the key data provider on campus, refering to staffs working for university, college, department-level offices, while the latter one is the key data demander, refering to the faculty members and students.

Table 2. User account types in of our campus information integration platform

Account type	Description
Admin	System administrator: in charge of user account and data management
Division	Key data provider: staffs working for university, college, department-level offices
Individual	Key data demander: faculty members and students

Two data management schemes were included in our system as shown in Table 3: data visibility and downloadability. When uploading the data, users can choose which level they prefer, and the other user can access and download their data accordingly.

Table 3. Data management schemes in of our campus information integration platform

Data visibility	Description	**Data downloadability**	Description
Public	Visible for all account types Data upload without size limit	**For everyone**	Downloadable for all account types
		Only for division	Downloadable only for division account type
		By request	Not downloadable, request can be made via email sending function embedded in the system
Private	Visible only to account owner and admin Data upload with size limit (total 1 gbit monthly)	**Not applicable**	Data can only be seen and downloaded by account owner and admin

3 Results

We used National Taiwan University, Taipei, Taiwan as our study case to demostrate how our four-data-leveled system works. More detailed information is provided in the following subsections in sequence.

3.1 1D Data

Figure 2 shows the 1D data uploading process. The first task for users is to select the data visibility and downloadability, then select their file to upload (see Figure 3). A small check box will pop up for them to confirm the upload details they provided. Then the system backend will check whether this is a new project with its file name. If there is a same file name in the database, an error sign will show. If not, the uploaded file will be reviewed by the admin. Once the admin approves the uploading request, the file will be shown on the display page (see Figure 4). If the admin disapproves the request, the user will get a notification and chance to re-upload the file under the same file name (i.e. project name).

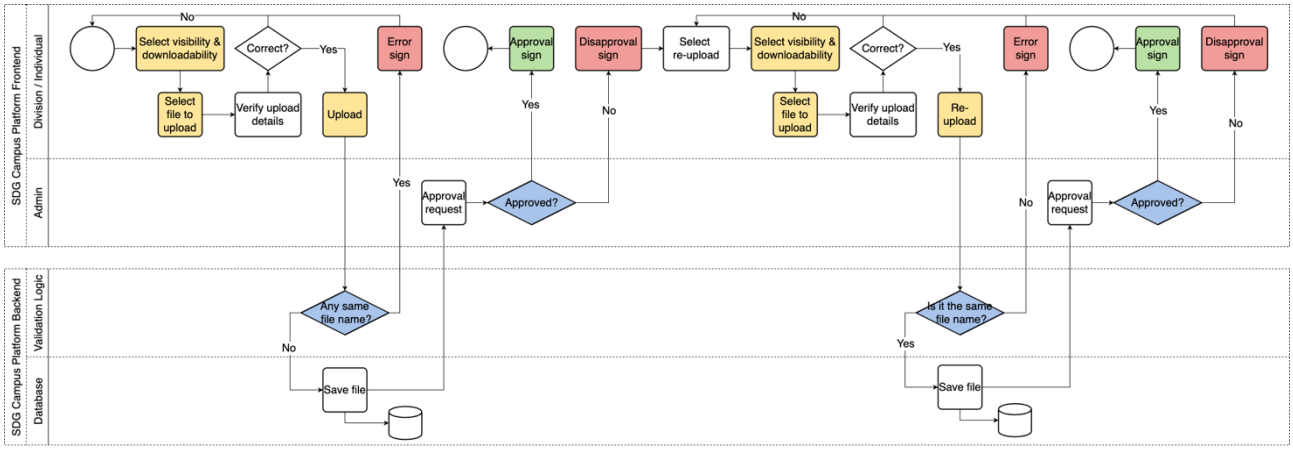

Figure 2. BPMN diagram of 1D data uploading process

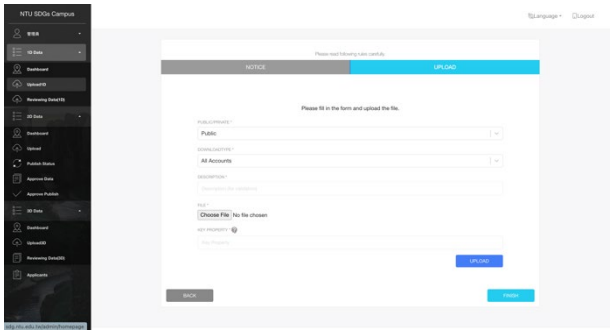

Figure 3. Screenshot of 1D data upload page

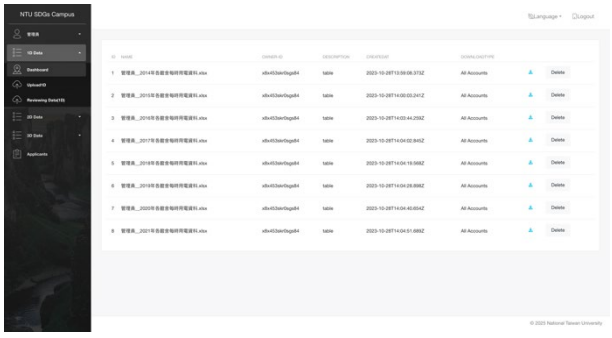

Figure 4. Screenshot of 1D data display page

The user can also select the available datasets and publish them via PowerBI Cloud for visualization. Figure 5 shows the 1D data publishing process, which is composed of the selection of dataset, logging in their PowerBI account, and confirming the publishing status. Figure 6 shows an example of visualizing the total annual building energy consumptions throughout the years.

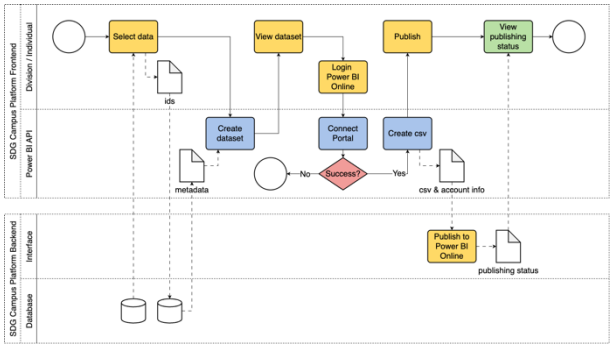

Figure 5. BPMN diagram of 1D data publishing process

Figure 6. Screenshot of 1D data visualization via PowerBI

3.2 2D Data

Figure 7 shows the 2D map uploading process. The key differences from 1D data are the selection of data type (i.e. point, line, polygon data) and select/ insert the key attribute for data binding between the uploaded maps and tabular data (see Figure 8). In this way, the metadata of campus maps can easily be enriched, while the users can still select the prefered dataset to download or publish with this binding method (see Figure 9).

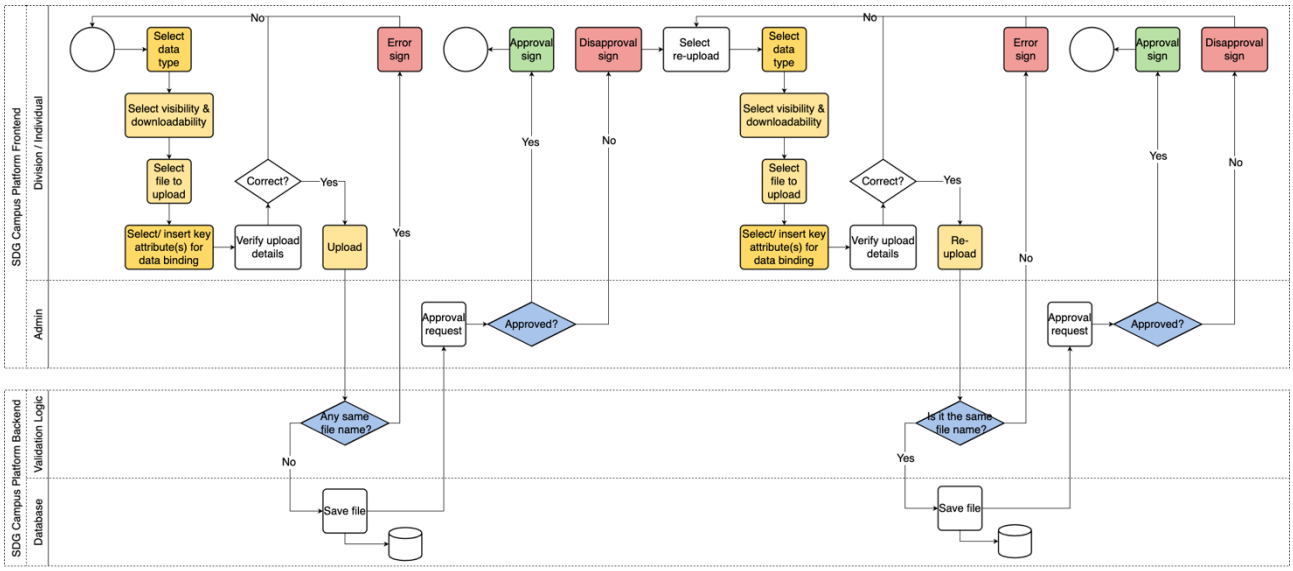

Figure 7. BPMN diagram of 2D map uploading process

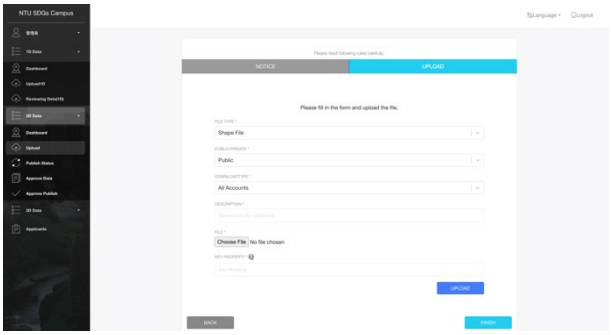

Figure 8. Screenshot of 2D data upload page

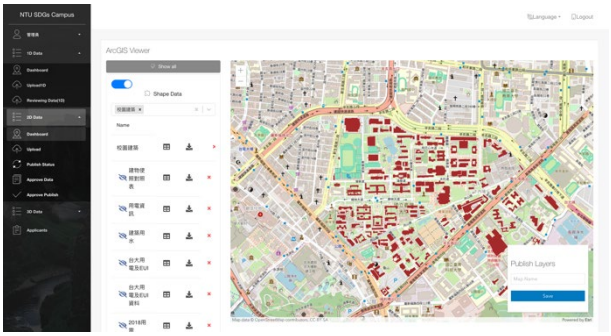

Figure 9. Screenshot of 2D data display page

Figure 10 shows the 2D data binding process. The key differences from 2D map uploading process are the selection of 2D map to be binded with and select the key attribute for data binding. For example, to bind the tabular data of individual annual/ monthly/ daily building energy consumptions with the 2D poloygon map of campus buildings, the building ID (i.e., uid) should be selected.

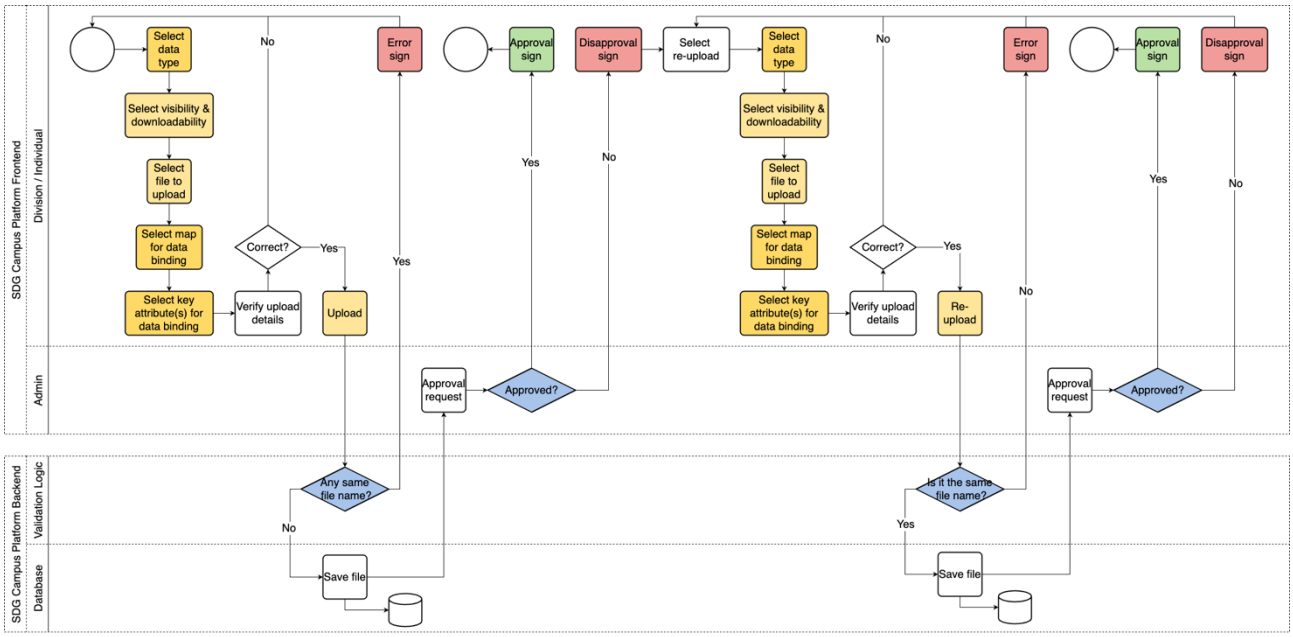

Figure 10. BPMN diagram of 2D data binding process

The user can also select the available datasets and publish them via ArcGIS Cloud for visualization. Figure 11 showns the 2D data publishing process, which is composed of the selection of dataset, logging in their ArcGIS account, and confirming the publishing status. Figure 12 shows an example of visualizing the energy performances of different buildings on the campus for comparison.

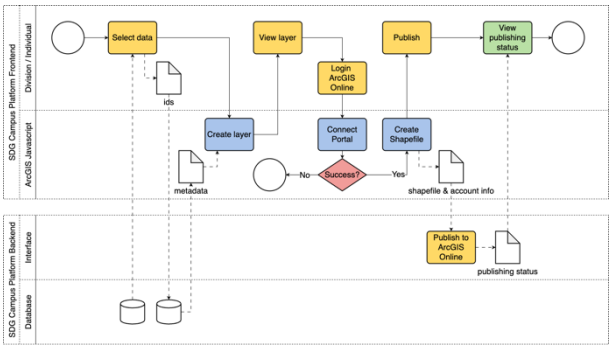

Figure 11. BPMN diagram of 2D data publishing process

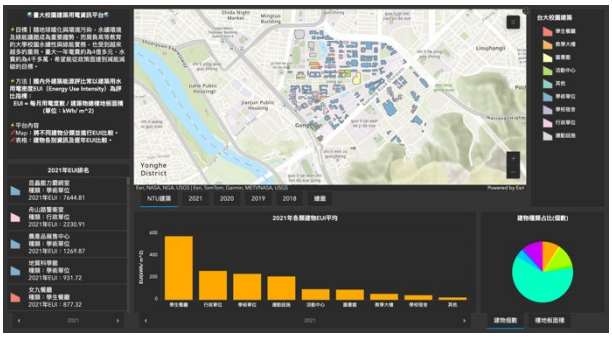

Figure 12. Screenshot of 2D data visualization via ArcGIS Cloud Dashboard

3.3 2.5D Data

The 2.5D data uploading process is the same with 1D one and the uploading page likewise (see Figure 13). After successfully uploading the 3D model to the database, the admin will manually publish the model via ArcGIS Pro, then the link of the model as a layer will be created and saved in the database, and the uploaded model can be viewed in the 3D environment as shown in Figure 14. Chen et al. (2023) work provides further discussions on the application scenario of 2.5D data.

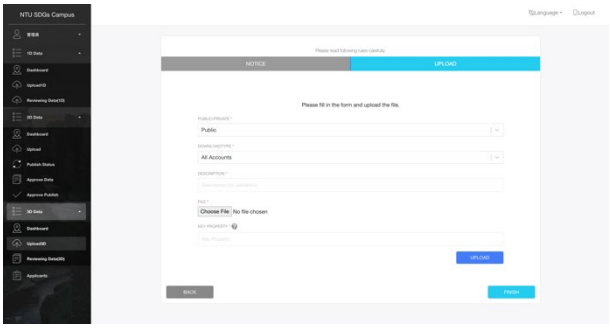

Figure 13. Screenshot of 2.5D data upload page

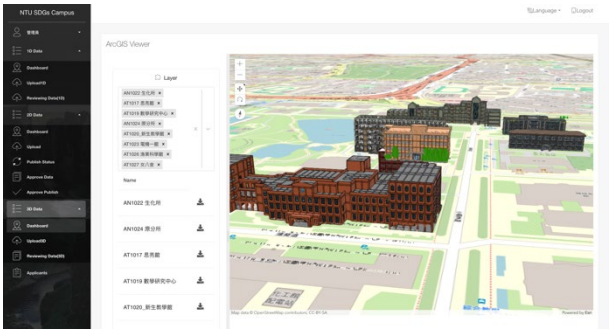

Figure 14. Screenshot of 2.5D data display page

3.4 3D Data

The 3D data on our campus information platform refers to detailed building models (e.g., BIM models) containing building objects at room levels. The integration of BIM-based sub-layer into the information integration platform is still under development. Meanwhile, some application scenario of our 3D data can be found in Chang et al. (2024) work and more detailed information concerning the integration of BIM models and other datasets (e.g., IoT data) can be found in Fu et al. (2025).

4 Conclusions

This study presents the development and implementation of a comprehensive information integration platform designed to visualize and manage campus sustainability data at National Taiwan University. By addressing the persistent challenges of data collection, integration, and management across diverse administrative units and user groups, the proposed system framework enables more effective tracking of environmental performance and supports informed decision-making for sustainability initiatives.

The platform's multi-level data structure—encompassing 1D, 2D, 2.5D, and 3D data—facilitates the organization and visualization of a wide range of sustainability indicators, from campus-wide energy consumption to room-level environmental metrics. The integration of user and data management modules ensures secure, flexible access for various stakeholders, fostering a culture of transparency and information sharing within the university community.

The case study at National Taiwan University demonstrates the platform's potential to streamline sustainability reporting, enhance stakeholder engagement, and support the university's strategic sustainability goals. As digital twin technologies and data integration practices continue to evolve, the proposed framework offers a scalable and adaptable solution for other higher education institutions seeking to advance their sustainability agendas.

Future work will focus on further integrating BIM-based 3D models and IoT sensor data, expanding the platform's capabilities for real-time monitoring and predictive analytics. Ultimately, this research contributes to the growing body of knowledge on digital solutions for campus sustainability and provides a practical roadmap for universities aiming to achieve greater environmental responsibility and operational transparency.

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Conflicts of Interest
The authors declare no conflict of interest.

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