



DIGITAL TWIN DATA INTEGRATION FOR FM WITH PRACTICAL IMPLEMENTATION

Felip Wang, Tomo Cerovsek
University of Ljubljana, Slovenia

Abstract

This study examines the integration of Digital Twin (DT) technology into Facility Management (FM) via Autodesk Tandem, focusing on connecting physical assets to digital models. By leveraging IoT data and real-time insights, the research demonstrates enhanced FM capabilities, including real-time monitoring, data visualization, and asset management. Using the Digital Built Environment Maturity Model (dbEMM), Autodesk Tandem achieves the Standard Operation maturity level, addressing the limitations of traditional FM systems. This work highlights DT's transformative potential to bridge physical-digital gaps, improving operational efficiency and providing a strong foundation for advancing DT-driven FM practices and innovations.

Introduction

The Digital Twin (DT) concept, introduced 20 years ago, has gained traction in recent years, particularly in the architecture, engineering, and construction (AEC) field (Hosamo et al., 2022). While early DT applications focused on product simulations (Tao et al., 2019), their adoption in buildings and IoT-integrated facilities now addresses critical challenges in operations and maintenance (O&M) (Wang et al., 2024), which is typically managed by Facility Management (FM) system. However, traditional FM systems often fall short of providing comprehensive access to building information assets. In contrast, Building Information Modelling (BIM) systems, supported by Common Data Environments (CDE), enable stakeholders to manage asset lifecycle (ALC) data, enhancing collaboration and interoperability (Sacks et al., 2018).

Nevertheless, BIM's focus on early design and construction stages limits its ability to integrate real-time data for O&M (Lu et al., 2020). DT technology implemented in the AEC industry can address this gap, providing a comprehensive solution for FM and asset information access. This solution offers stakeholders improved insights into asset status, including energy consumption, environmental quality, and equipment operation conditions.

Research questions guiding this study include:

1. What are the current capabilities and features of FM systems?
2. How does DT improve FM's accessibility to real-time data?
3. How can data be effectively connected from IoT devices in the physical twin to the virtual twin?
4. What functions of FM systems can DT platforms replicate, and what are their limitations?

Research Process

The case studies and implementations are critical because this study aims to leverage DT technology to integrate building assets' information and enhance FM real-time data access and control. To achieve this, a series of interconnected research processes have been established, analyzing an FM platform utilized in a construction company and implementing a DT platform applied to a physical building asset. These processes are designed to integrate three complementary dimensions: foundational, analytical, and implementational.

1. **Foundational Dimension:** This phase establishes groundwork by selecting the DT platform and defining its maturity level based on existing theories. Autodesk Tandem is evaluated for its advantages over other platforms, with its maturity level and target development stage clarified using the Digital Built Environment Maturity Model (dbEMM). This dimension provides a framework for DT platform features to enhance the FM functions, serving as a reference for the subsequent dimensions.
2. **Analytical Dimension:** This section evaluates the current FM system used by the collaborating construction company, focusing on its technological readiness for real-time data integration and asset virtualization. The case involves a SCADA-based system, a common tool for monitoring and controlling building operations. While not BIM-based or visually modeled, it serves as a maturity reference for data-centric DT implementation in FM. This analysis bridges theoretical and practical perspectives, identifying strengths and gaps. The findings guide the Implementational Dimension by informing how DT technology can be better aligned

with FM requirements in the context of UL FGG’s DT development.

3. **Implementational Dimension:** Building on the foundational and analytical phases, this stage integrates IoT data from the physical building asset into the DT platform. Key activities include configuring the DT model to accurately represent building assets, establishing real-time data connections for a functional digital twin, and validating the integration through simulations and performance testing. This ensures the DT supports FM with virtual representation, live data, and actionable insights for informed decision-making.

Foundational Dimension

This study adopts the “Digital Built Environment Maturity Model” (Papic and Cerovsek, 2019) as a basis for evaluating a DT platform. In this research, the model is applied within a BIM-based workflow, and the three maturity vectors considered are:

1. **ADC (Areas of Digital Capability):** Focuses on lifecycle data management, requiring accurate data, suitable levels of detail (LOD), and effective system classification.
2. **SOE (Supporting Organization Environment):** Examines the readiness of organizations to support DT projects, emphasizing skilled teams, streamlined processes, and enabling technologies. In this study, the BIM model reflects a structured SOE, integrating data from multiple contributors.
3. **DMS (Digital Twin Maturity Stages):** Defines the progression of DT capabilities, from basic data integration to advanced real-time automation and intelligence. This research aims to implement a DT with the DT Standard Operation maturity level.

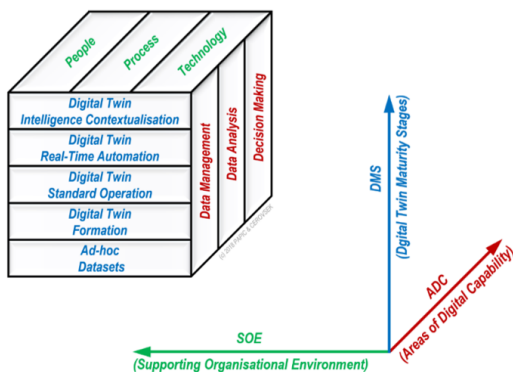


Figure 1: Digital Built Environment Maturity Model (dbEMM) (Papic and Cerovsek 2019)

Within **BIM-based workflows**, Digital Twin (DT) technology is typically applied as a **post-BIM** stage, initiated after design and construction—during the

operation and maintenance (O&M) phase. The **BIM Execution Plan (BEP)** defines project information requirements, with the **Asset Information Model (AIM)** serving as the final deliverable, bridging the BIM workflow and O&M phase. While AIM provides a critical foundation, it alone does not constitute a DT.

The **Implementational Dimension** demonstrates DT execution at the **DT Standard Operation** stage. The process begins with integrating the BIM model into the DT platform, collaboratively developed within an organizational structure aligned with the **Supporting Organization Environment (SOE)**. Ad-hoc datasets are consolidated into a central model to meet data quality standards for FM use. By integrating the three **dbEMM** vectors—**ADC**, **SOE**, and **DMS**—the DT progresses from formation to full operational deployment, enabling real-time data flow, asset management, and informed decision-making in FM systems.

DT Platform Selection

Selecting a suitable DT platform is critical to integration, scalability, and FM alignment. This study applies a six-step method to guide evaluation and reduce bias from a small research team.

Step 1: Define the Purpose: Compare DT platforms for FM with integrated BIM and IoT capabilities.

Step 2: Set Selection Criteria: Based on the dbEMM framework, platforms were evaluated by the criteria:

- Relevance to FM workflows
- DT maturity and functional scope
- Compatibility with BIM and IoT

Step 3: Initial Platform Survey: platforms included:

- Unity (AR/VR visualization)
- Siemens Building X (smart building solution)
- Bentley iTwin (infrastructure-focused)

Step 4: Filtering: Platforms were excluded if they lacked FM-specific functionality, required extensive customization, or were oriented toward other domains.

Step 5: Final Selection

- **Autodesk Tandem:** FM-oriented BIM integration
- **Dalux:** Mobile-ready with BIM/FM features
- **Microsoft Azure:** IoT-based, scalable DT framework
- **BIMcollab:** Entry-level BIM tool (baseline)

Step 6: Maturity Evaluation Standard: Each platform was evaluated using dbEMM with a simplified Low–Medium–High scale. The SOE "people" component was excluded to reduce bias, focusing rather on how platforms support collaboration and data integration. The evaluation results are shown in Table 1 and 2. It is evident that Autodesk Tandem received the highest score in Table 2, making it the chosen testing platform for the study.

Table 1: DT Platform Evaluation with dbEMM

Component	Platform Evaluation	Component	Platform Evaluation
ADC		SOE	
Data Managing	Evaluate the platform's support for organizing and classifying data from BIM, IoT, and other sources.	Process	Evaluate how well the platform integrates into existing FM workflows and supports automation.
Data Analysis	Assess the platform's ability to support real-time data analysis, predictive analytics, and reporting for FM optimization.	Technology	Assess the platform's scalability, compatibility with IoT, and cloud support for efficient asset management and operations.
Decision Making	Review how the platform translates insights into actionable decisions, such as through real-time dashboards or automated alerts.	DMS	
		DT Maturity Levels	Assess the platform's support for the maturity level of DT development.

Table 2: Platform Maturity Evaluation Standard Aligned with dbEMM

Evaluation Metric	Autodesk Tandem	Dalux	Microsoft Azure	BIMcollab
Data Managing	High: Seamless integration with BIM ecosystem, strong data classification and organization.	Med: Model - Plan integration with BIM, limited data management. organization capabilities.	High: Extensive data management across cloud, integration with BIM.	Low: Primarily focused on BIM issue tracking, lacks broad data management.
Data Analysis	High: Advanced real-time analytics, and predictive capabilities for asset management.	Med: Basic data analysis for FM, limited predictive analytics and integration.	High: Strong data analytics, cloud-based processing.	Low: Minimal data analysis capabilities, more focused on issue management.
Decision Making	High: Real-time dashboards, and automated decision-making based on integrated data.	Med: Supports basic decision-making, lacks automated decision features.	High: Robust decision-making with cloud integration and real-time data.	Low: Lacks decision-making features beyond issue tracking.
Process	High: Strong support for FM processes, and seamless integration with BIM and IoT devices.	Med: Integration with FM workflows, more construction-focused, no real-time support.	Med: Strong integration with cloud but less focus on FM-specific workflows.	Low: Primarily BIM-focused, limited support for FM processes.
Technology (IoT, Cloud, Scalability)	High: Robust cloud-based platform with extensive IoT device integration.	Med: Cloud support but limited scalability no support / advanced IoT integration.	High: Strong cloud infrastructure and IoT integration, highly scalable.	Low: Limited scalability, cloud and IoT integration, not a primary focus.
Digital Twin Maturity	High: Full support from stage 1-3, some advanced Real-Time features of stage 4.	Med: Full support from stages 1-2, some advanced Real-Time features of stage 4.	High: Full support for stages 1-3, stage 4 based on its cloud no FM feature.	Low: Lacks full digital twin support, more focused on issue tracking and BIM.
Other Highlights	Advanced custom. (APS), seamless BIM integration, and FM-focus IoT capability.	Mobile-first approach and comprehensive tools for construction and FM.	Scalable, versatile cloud platform with robust analytics and AI capabilities.	Exceptional issue tracking and integration with leading BIM tools but limited in broader digital twin application.

(Note: This assessment is not about the platform's capabilities, but rather its suitability for a particular project.)

Analytical Dimension

The analytical dimension assesses SCADA as implemented in a cooperating company's office building. Though it lacks a BIM-based model and full ALC integration, SCADA demonstrates effective real-time monitoring. It serves as a valuable case for evaluating digital readiness and illustrates the progression from BIM-based FM systems toward Digital Twin adoption.

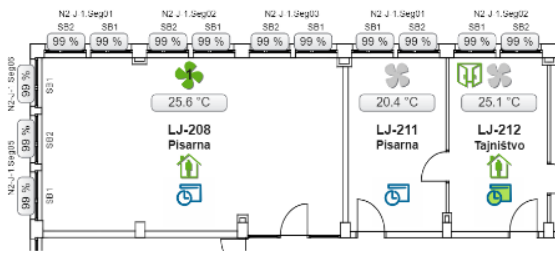


Figure 2: SCADA's User Interface

The presented implementation of the SCADA system primarily focuses on **monitoring and controlling building assets**, strongly emphasizing optimizing energy consumption and maintaining indoor environmental quality. Its user interface provides a comprehensive overview of building performance, including:

1. **Outdoor Environmental Monitoring:** Temperature, wind speed, precipitation, and light intensity at three different elevations.
2. **Indoor Environment Monitoring:** Indoor temperature, window opening status, and room occupancy.
3. **System Automation:** HVAC adjustments based on outdoor weather conditions. Automated sunblind adjustments to optimize sunlight penetration based on real-time light intensity sensors.

The key features of SCADA are:

1. **Integration with Building Assets:** SCADA connects seamlessly with the HVAC and sunblind systems, ensuring effective management and control of indoor temperature and energy efficiency.
2. **Real-Time Data Accessibility:** Users have access to timely data charts and records that visualize energy usage, allowing informed decision-making to reduce energy consumption and CO₂ emissions.
3. **Automation Workflow:** SCADA automates workflows, such as: Regulating HVAC operation in response to weather changes and adjusting sunblind settings dynamically to manage heat and light levels indoors.



Figure 3: Timely data record chart

The Limitations of SCADA:

1. **Lack of a Virtual Model:** SCADA does not provide a virtual replica or AIM of building assets, which limits its functionality as a comprehensive DT platform for ALC-oriented FM.
2. **Data Contextualization Gaps:** While SCADA offers robust real-time monitoring, it does not include advanced features like predictive analytics or AI-driven decision-making typically associated with higher DT maturity stages.

Overall, SCADA represents a robust FM system, excelling in real-time monitoring, energy optimization, and part of automation. However, its lack of an AIM and advanced data contextualization limits its classification as a full DT platform. To bridge this gap, Autodesk Tandem will use SCADA as a case study, leveraging its features to innovate the parameters required for an Asset Information Model. By integrating SCADA's operational data streams into a DT framework, Tandem can establish data delivery pipelines for real-time utilization and asset virtualization.

By leveraging SCADA's operational strengths, Autodesk Tandem can build a DT framework that bridges SCADA's current limitations. This framework will create a comprehensive virtual model, integrating real-time data for smarter, data-driven operations.

Implementational Dimension

This dimension focuses on establishing real-time data connections from IoT devices to the selected DT platform, Autodesk Tandem. It employs two data delivery methods and explores an additional pipeline to ensure robust integration.



Figure 4: AIM of UL FGG in Tandem

Physical Asset and Data Sources

The Faculty of Civil and Geodetic Engineering at the University of Ljubljana (UL FGG) serves as the physical asset for linking the real-world environment with the DT. A Digital Twin requires both real-time data from physical assets and an AIM. In this study, the AIM is obtained from another research group and is in the Industry Foundation Classes (IFC) format, exported from ArchiCAD. After uploading the IFC model to Autodesk Tandem, streaming tests focus on integrating IoT sensor data and external weather data streams into Tandem.

Two primary data sources are used:

1. **OpenWeather Data:** External weather data is accessed via OpenWeather’s API URL for real-time integration.
2. **HOBO IoT Sensors:** Installed in Room 40 of the UL FGG building, these sensors provide data on temperature, humidity, CO2 levels, and light intensity. Due to restricted API access, data delivery relies on CSV pipelines with an FTP server.

HOBOLink's restricted data sharing presents the following challenges:

1. Restricted API access for HOBOLink complicates direct integration, requiring CSV-based pipelines.
2. Synchronizing timestamps and aligning parameter definitions ensure consistent data representation within the DT.

Tandem Connect for Data Integration

Tandem Connect serves as an auxiliary tool within the Autodesk Tandem ecosystem, designed specifically to facilitate data integration from external IoT platforms into the DT model. As a visual coding platform, Tandem Connect enables users to build and manage data pipelines through intuitive, JSON-based nodes. It complements Autodesk Tandem by streamlining the ingestion, transformation, and synchronization of real-time data from multiple sources. Its primary function is to bridge the gap between raw sensor data and the DT’s virtual asset model, ensuring seamless integration and usability for FM applications.

1st Data Delivery Pipelines— API URL Pipeline

This pipeline tests the API URL and Autodesk Tandem's connectivity to ensure consistent data delivery. Tandem Connect structures the workflow using four key node types: Stream, Service, Converter, and Connector. Each node has a specific role in the pipeline, and users can assign custom names to differentiate them. The nodes in the pipeline are as follows.

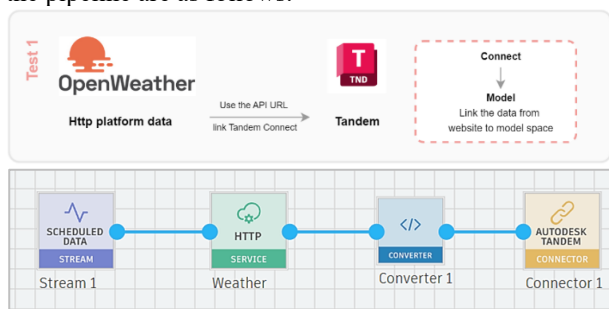


Figure 5: First Testing Pipeline- API URL

1. **Stream Node ("Stream1"):** Schedules data delivery, allowing users to configure timing, routine settings, and synchronization; acts as the trigger for the entire pipeline, initiating data flow.
2. **Service Node ("Weather"):** Retrieves real-time weather data from the OpenWeather API using the

- HTTP "GET" method; enables seamless data transfer via the API URL.
3. **Converter Node:** Processes JSON data retrieved from the API by defining parameters such as the device name ("Weather") and dataset fields (e.g., temperature and humidity); ensures the extracted data aligns with Autodesk Tandem's requirements.
4. **Connector Node:** Links the processed data to the Autodesk Tandem model using RESTful protocols; requires APS credentials (Client ID and Client Secret) and the virtual twin’s facility ID to establish secure connectivity.

Pipeline Highlights

“Stream1” triggers the pipeline and initiates data synchronization. A pop-up window displays the delivery status for confirmation.

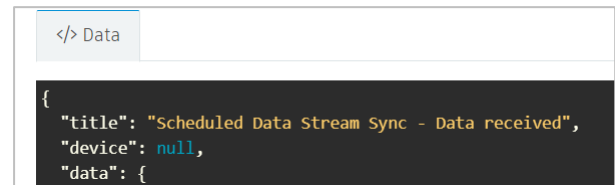


Figure 6: Data received in “Stream1”

The API URL is entered into “Weather”, which retrieves real-time weather data using the JSON GET method for seamless integration with the Tandem system.

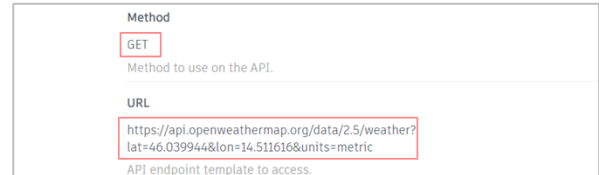


Figure 7: Option configuration in Weather HTTP node

“Converter1” defines and validates the data to ensure proper alignment with Tandem's JSON structure, enhancing compatibility and ensuring accurate data synchronization.

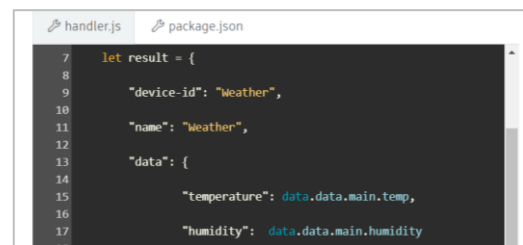


Figure 8: Specify the data set in the converter

Finally, the “Connector1” uploads the processed data to the virtual twin in Tandem, ensuring that the same APS protocol (Client ID and Client Secret) facilitates secure connectivity across the three interconnected platforms. This step ensures compatibility while enabling synchronized operations between platforms, completing the pipeline effectively.

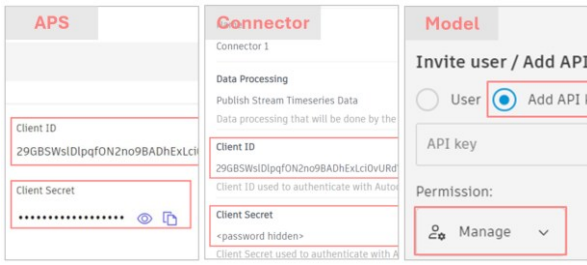


Figure 9: Data delivery API setting

Additionally, the facility ID, found at the end of the URL on the Tandem model webpage, ensures accurate data mapping to the correct virtual model. Copy the "urn" from the URL and paste it into the Connector node to establish the linkage effectively.

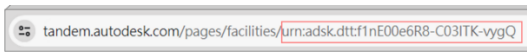


Figure 10: Add Facility ID in the Connector node

2nd Data Delivery Pipelines— CSV Pipeline

This pipeline integrates data from IoT sensors using CSV files delivered via an FTP server, offering an alternative method for data streaming. CSV remains a widely used and mature format in the industry, providing flexibility for devices with limited direct integration capabilities. The pipeline involves three types of IoT sensors installed in Room 40 of the UL FGG building, as shown below.

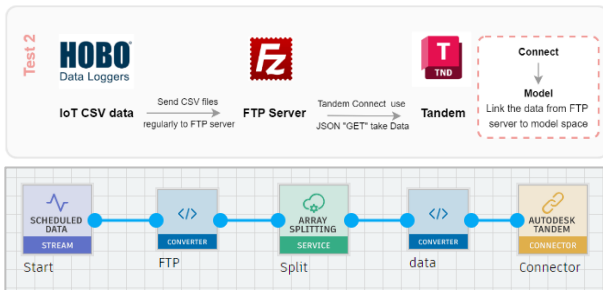


Figure 11: Second Testing Pipeline - CSV

1. **Type A:** Air quality sensor mounted on walls, measuring temperature, humidity, and CO2 levels.
2. **Type B:** Indoor environmental sensor on walls, measuring temperature, humidity, CO2, light intensity, and dew point.
3. **Type C:** Lighttemp sensor on desks, measuring temperature and light intensity.

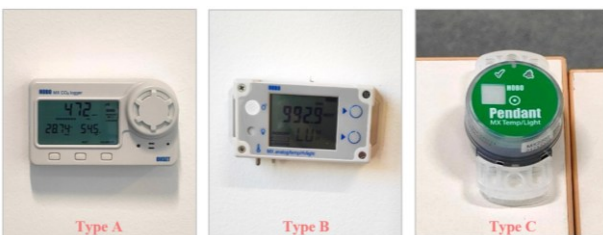


Figure 12: The type of sensors in the physical asset

These sensors regularly send data to HOBOLink, the IoT platform, which generates CSV files. The FTP server retrieves these files for integration into Autodesk Tandem.

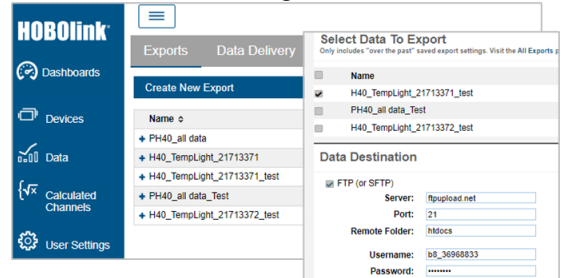


Figure 13: Data exporting from HOBOLink to FTP server

The workflow of the CSV pipeline is as follows:

1. **Stream Node ("Start"):** Establishes a connection to the FTP server and schedules data retrieval. Users input the FTP server's address and configure trigger settings.
2. **FTP Node:** Accesses the FTP server to retrieve CSV files and converts their content into JSON format. This step includes creating an FTP client instance, filtering files, and logging the process.
3. **Split Node:** Organizes data streams based on sensor type to ensure clarity and alignment with corresponding devices.
4. **Converter Node ("Data"):** Processes the JSON data by defining device names and parameters (e.g., humidity, temperature, CO2); validates the data to ensure accuracy and eliminate incomplete datasets; adjusts timestamps to UTC, accommodating timezone differences (e.g., UTC+2 for Ljubljana during summer).
5. **Connector Node:** Links the processed data to the virtual twin in Autodesk Tandem. Requires APS credentials (Client ID and Client Secret) and the facility ID of the virtual twin.

Pipeline Highlights

"Start" Triggers the pipeline, schedules data synchronization with the FTP server, and ensures efficient task execution for initial stages.

```
1 {
2   "host": "ftpupload.net",
3   "port": 21,
4   "username": "b8_36968833",
5   "password": "25333293",
6   "directory": "/htdocs",
7   "processed": "/processed"
```

Figure 14: Specify the FTP server's address in "Start"

The **"FTP"** node Retrieves CSV files from the server, converting them into JSON format for seamless integration into Tandem; ensures compatibility and accuracy.

```
const fileContents = await fs.readFile(localFilePath, 'utf-8');
logger.log('File Contents:\n${fileContents}');

const jsonArray = await csvtojson().fromString(fileContents);
logger.log('CSV content converted to JSON');
```

Figure 15: Convert CSV to JSON

“Data” processes and validates JSON data, defining parameters like temperature, humidity, and CO₂; timestamps are adjusted to UTC for consistency across datasets

```
// Convert the provided date to RFC 3339 format and adjust to Slovenia timezone
const dateString = data.result.data.Date;
const date = new Date(dateString);
date.setHours(date.getHours() - 2); // Adjust timezone by subtracting 2 hours
const rfc3339Timestamp = date.toISOString(); // Convert to RFC 3339 format

// Create and return an array containing data for all devices with prefixed IDs
const results = devices.map(device => ({
  "device-id": device.id,
  "data": {
    "name": device.name,
    "Temperature": temperatureValue,
    "RH": rhValue,
    "CO2": co2Value,
    "ts": rfc3339Timestamp
  }
}));
```

Figure 16: The codes in the “Data” node

Configuring the data in the Tandem model

IoT devices send data through Tandem Connect to the Tandem model, aligning with specific properties. The virtual twin is classified based on project requirements, with IoT parameters updated for accurate asset mapping, ensuring seamless integration and effective Digital Twin asset management.

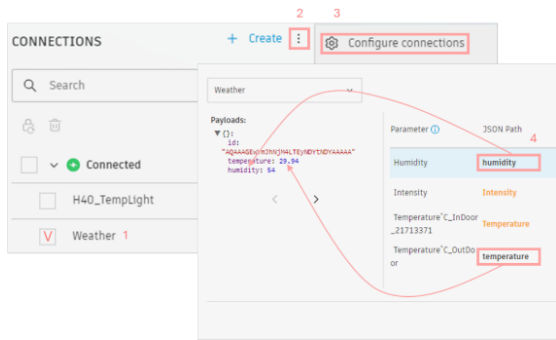


Figure 17: Matching data to the properties

Data Visualization

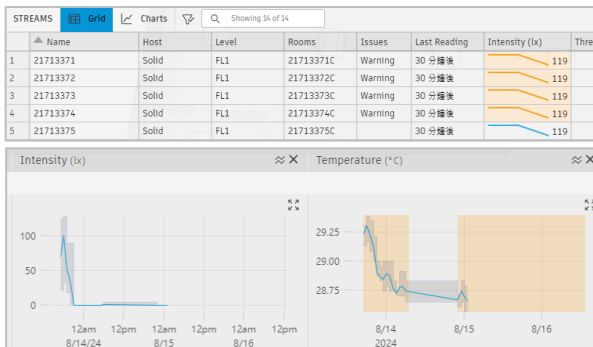


Figure 18: Timely data in Grid and Charts

Connected to a virtual twin, the DT enables real-time data tracking, management, and operational efficiency. Configuring data layout and visualization enhances FM by improving monitoring, oversight, and decision-making processes. Features like data grids allow users to set thresholds for environmental measurements, with color-coded alerts highlighting anomalies for quick action and better resource allocation. This seamless integration ensures timely insights into asset conditions and helps prevent issues from escalating effectively.



Figure 19: Dashboard

Autodesk Tandem provides advanced visualization tools such as heatmaps and cluster classification to optimize data management. The dashboard offers quick access to frequently used asset statuses, allowing users to monitor critical information instantly and efficiently. Additionally, data can be exported in a printable format for reporting, documentation, and enhanced collaboration with project teams.

Limitations and Solutions

While Autodesk Tandem provides a comprehensive DT interface, it currently lacks support for online model merging. To address this limitation, this study utilized IfcOpenShell to merge Room 40’s model, exported from Revit, with the UL FGG’s IFC model. This workaround enables seamless integration of different model formats, extending Tandem’s capabilities and ensuring a unified representation of building assets.

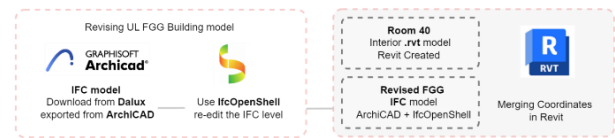


Figure 20: Workflow of IFC editing of the study

Other Notes— HOBOLink Integration & API Success

A new method using HOBOLink for direct IoT sensor access is under testing, with instructions detailed in the user guide. A local script in Julia successfully retrieved real-time data after obtaining the correct API user ID from the UL FGG Room 40 manager. Plans are underway to adapt these scripts for Autodesk Tandem Connect nodes.

Challenges and Potential Benefits

Differences between local coding environments and Tandem Connect nodes have delayed data mapping integration and synchronization efforts. However, HOBOLink promises machine-to-machine (M2M) communication, reducing data delivery errors, enhancing reliability, and improving operational efficiency in asset management processes and decision-making workflows.

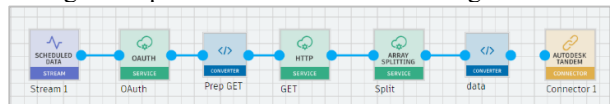


Figure 21: The OAuth Pipeline

Conclusion

This research demonstrated the practical application of Digital Twin technology in Facility Management using Autodesk Tandem, highlighting its potential as a BIM-oriented alternative to traditional FM systems. Compared to conventional FM tools reliant on static data, Tandem enables seamless synchronization between real-time inputs and virtual models, significantly enhancing asset management and operational decision-making.

Achieving Research Objectives

The study validated Autodesk Tandem's capability to integrate IoT data into virtual twins, enhancing core FM functions such as real-time monitoring, energy tracking, and data visualization. Tools like heatmaps, grids, and BIM property forms provided stakeholders with actionable insights and a clear understanding of building performance. The platform's flexibility was demonstrated through the implementation of two distinct data connection pipelines, highlighting its adaptability across FM scenarios.

Final Achieved dbEMM Maturity Level

The evaluation using the Digital Built Environment Maturity Model (dbEMM) showed Autodesk Tandem's progression across three vectors:

1. **ADC:** High maturity, reflecting strong data integration and real-time utilization.
2. **SOE:** Medium-high maturity, with effective workflows and partial organizational readiness.
3. **DMS:** Medium-high maturity, indicating successful DT formation and operation with advanced visualization.

Key Improvements and Successes

1. **Enhanced Data Integration:** Autodesk Tandem facilitated the seamless connection of IoT devices to virtual models, enabling real-time updates and synchronized operations.
2. **Improved Visualization:** Advanced tools provided clear and interactive representations of building data, improving stakeholders' ability to monitor and manage assets effectively.
3. **Operational Efficiency:** By bridging the physical and virtual worlds, Autodesk Tandem streamlined FM processes, reduced manual interventions, and enhanced decision-making.

Challenges and Future Directions

Despite its success, the platform faces challenges in areas like real-time analytics, seamless model merging, and the need for advanced training. Addressing these challenges requires further development, particularly in enhancing data synchronization accuracy and integrating AI-driven predictive maintenance tools.

Final Thoughts

This study demonstrates Autodesk Tandem's value in enhancing FM through BIM-based DT integration, real-time data synchronization, and improved asset visualization. Compared to traditional DT adoption in FM within the AEC field, this approach advances implementation into the operational phase by leveraging BIM from early project stages, ensuring vital asset information is carried throughout the asset lifecycle (ALC). By applying the dbEMM framework, the study provides a structured method to evaluate DT maturity and platform suitability. The findings offer a transferable model for researchers to assess platform readiness, design integration pipelines, and align digital twin strategies with FM goals. The Autodesk Tandem case thus serves as a practical reference for replicable DT-FM implementations in both academic and industry contexts.

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