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# BIM-Integrated Digital Twin Framework for Real-Time Monitoring of Sustainable Building Infrastructure

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**Abstract**

The increasing demand for sustainable building infrastructure has created the need for intelligent monitoring systems capable of evaluating building performance throughout its operational lifecycle. Conventional Building Information Modeling (BIM) primarily supports the digital representation of building components and project information, while its integration with Internet of Things (IoT) technologies and Digital Twin systems provides opportunities for continuous monitoring and performance assessment. This paper proposes a BIM-integrated Digital Twin framework for real-time monitoring of sustainable building infrastructure. The proposed framework combines BIM-based building information, IoT-enabled sensor networks, cloud-based data management, real-time analytics and digital visualization to create a connected representation of physical building assets. The system considers important operational parameters, including energy consumption, indoor environmental conditions, equipment performance, water utilization and structural health. Sensor-generated information is synchronized with the corresponding building components in the digital environment to support condition monitoring, anomaly identification, predictive maintenance and operational optimization. The framework also incorporates sustainability assessment capabilities to support energy-efficient building operation and resource management. A layered architecture is developed to address data acquisition, communication, integration, analytics and decision support. The proposed framework is evaluated through a conceptual validation strategy considering data synchronization, monitoring reliability, interoperability, operational efficiency and sustainability indicators. The study highlights the potential of combining BIM and Digital Twin technologies to improve building operation and maintenance while supporting sustainable infrastructure management.

**Index Terms—** Building Information Modeling, Digital Twin, Internet of Things, Sustainable Building Infrastructure, Real-Time Monitoring, Smart Buildings, Predictive Maintenance, Energy Management.

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## I. INTRODUCTION

The construction industry is experiencing significant technological development through the adoption of digital engineering, intelligent monitoring systems and sustainable infrastructure management practices. Modern buildings contain interconnected systems involving structural components, electrical installations, heating, ventilation and air conditioning (HVAC), lighting, water distribution and other operational facilities. Managing these systems efficiently requires continuous access to accurate building information and operational performance data.

Traditional building management approaches often depend on periodic inspections, manual measurements and independent monitoring systems. These approaches may create information gaps between building design information and actual operational conditions. Building managers may also face difficulties identifying equipment abnormalities, evaluating energy consumption patterns and coordinating maintenance activities across different building systems.

Building Information Modeling provides a structured digital representation of building geometry, components, specifications and associated information. BIM has become an important technology for information management across architecture, engineering and construction activities. However, a conventional BIM model does not automatically represent the continuously changing operational conditions of a physical building.

Digital Twin technology extends the capabilities of digital building representations by connecting a physical asset with its virtual counterpart through sensor data, communication systems and analytical processes. The digital representation can be updated using information received from the physical environment, enabling improved monitoring and decision-making.

Nguyen and Adhikari [1] examined the relationship between BIM and Digital Twin technologies and highlighted the role of BIM in supporting the development of digital representations for construction applications. Radzi et al. [2] also identified different relationships between BIM and Digital Twin technologies and discussed their applications across planning, design, construction, operation and maintenance.

The integration of IoT sensors with BIM-based Digital Twin systems provides opportunities to monitor building conditions continuously. Sensors can collect information about temperature, humidity, energy consumption, equipment operation, vibration, occupancy and other environmental or structural parameters. This information can be transmitted to a central platform and associated with the corresponding building components.

**A. Research Objectives**

The primary objectives of this study are:

1. To develop a BIM-integrated Digital Twin framework for sustainable building infrastructure monitoring.
2. To establish a real-time data acquisition and synchronization approach using IoT-enabled sensing systems.
3. To integrate building information, environmental monitoring and equipment performance data within a common digital platform.
4. To support anomaly identification and predictive maintenance through data analytics.
5. To improve building energy management and operational sustainability through continuous performance monitoring.
6. To identify implementation challenges associated with interoperability, data quality, connectivity and system scalability.

### B. Research Contributions

The proposed study contributes a conceptual framework connecting BIM, IoT sensing, cloud-based data management and Digital Twin analytics for building operation and maintenance.

It also establishes an integrated monitoring approach for building energy consumption, indoor environmental quality, water utilization, equipment condition and structural health.

An additional contribution is the consideration of sustainability-oriented decision support, connecting real-time operational information with building maintenance and resource management activities.

### C. Organization of the Paper

The remainder of this paper is organized as follows. Section II discusses the related literature. Section III presents the proposed BIM-integrated Digital Twin framework. Section IV explains the system architecture and technological components. Section V discusses real-time monitoring applications. Section VI describes the implementation methodology. Section VII presents the evaluation strategy and technical discussion. Section VIII examines sustainability implications and practical challenges. Section IX discusses limitations and future research directions. Section X concludes the study.

## II. LITERATURE REVIEW

### A. Building Information Modeling in Digital Construction

Building Information Modeling is a collaborative process used to create, manage and exchange building information throughout different stages of a construction project. BIM supports the integration of geometric information, material specifications, component properties, construction documentation and facility-related information.

The adoption of BIM has improved coordination among architects, structural engineers, building services engineers and construction professionals. It also provides a foundation for digital information continuity during construction and facility management.

Nguyen and Adhikari [1] examined the role of BIM in integrating Digital Twin technology into building construction. Their literature review identified the potential of BIM to provide structured building information that can support digital representations and operational decision-making.

However, traditional BIM models are generally created around design and construction information. Without integration with operational data sources, they may not accurately reflect continuously changing physical conditions.

Consequently, BIM should be extended through appropriate information exchange mechanisms, sensor integration and data synchronization to support operational Digital Twin applications.

### B. Evolution of Digital Twin Technology

Digital Twin technology represents a physical asset through a corresponding digital environment connected by information exchange. Unlike a static three-dimensional

model, a functional Digital Twin can incorporate changing operational information to support condition monitoring, analysis and decision-making.

The relationship between BIM and Digital Twin technologies has become an important research area in the architecture, engineering, construction and operation sectors.

Radzi et al. [2] examined the relationship between BIM and Digital Twin through a systematic literature review. Their study identified different conceptual relationships and emphasized the need for clearer understanding of how the technologies work together.

The integration of BIM with IoT, data analytics and simulation systems enables building information models to become more responsive to actual operational conditions.

**C. IoT-Based Building Monitoring**

The Internet of Things provides communication capabilities between physical sensing devices and digital information platforms.

In building environments, IoT sensors can monitor temperature, humidity, illumination, occupancy, energy consumption, water flow, pressure and equipment conditions.

The information collected from these sensors can be transmitted through wireless or wired communication networks and stored in a centralized data management system.

The integration of IoT with Digital Twin technologies enables building operators to monitor operational conditions without depending entirely on manual inspections.

Kang and Mo [5] proposed a comprehensive Digital Twin framework for building environment monitoring, emphasizing real-time data connectivity and predictability. Their study also examined a prototype for monitoring environmental performance in existing buildings.

**D. Digital Twin for Energy-Efficient Buildings**

Energy management is an important component of sustainable building infrastructure.

Buildings consume energy through HVAC systems, lighting, electrical equipment, elevators and other operational facilities. Inefficient equipment operation and inappropriate control settings may increase energy consumption.

A building Digital Twin can integrate information from energy meters, environmental sensors and building management systems to support performance monitoring.

Cespedes-Cubides and Jradi [3] reviewed building Digital Twin applications related to operational energy efficiency. They identified component monitoring, anomaly detection, operational optimization, predictive maintenance and scenario simulation as important application areas.

The integration of energy monitoring with BIM allows operational information to be associated with individual spaces, systems and equipment. This enables more detailed examination of building energy performance.

**E. Structural Health Monitoring Through Digital Twins**

Structural health monitoring involves evaluating the condition and performance of building structures using sensors and analytical techniques.

Structural monitoring may include vibration measurements, displacement monitoring, strain observations, temperature measurements and other structural response information.

Integrating structural sensor information with BIM enables engineers to associate monitoring observations with individual structural components.

Hu et al. [6] proposed an intelligent BIM-enabled Digital Twin framework for real-time structural health monitoring using wireless IoT sensing, digital signal processing and structural analysis. Their research demonstrates the importance of integrating sensor processing and structural engineering knowledge into monitoring systems.

This approach provides an important foundation for extending BIM-based Digital Twin systems beyond visualization towards structural condition assessment.

**F. Sustainable Operation and Maintenance**

Sustainable building operation requires efficient coordination of maintenance, energy use, environmental performance and building services.

Jiao et al. [7] proposed a Digital Twin-based sustainable operation and maintenance framework for building infrastructure. Their research integrated Bayesian network and random forest methods for analysing operational factors and predicting energy consumption-related conditions. The proposed approach was illustrated using a real-world gymnasium application.

This research demonstrates the relevance of combining building operational data with analytical techniques to improve maintenance and energy management decisions.

**G. Digital Twins in Sustainable Construction**

Digital Twin applications in the built environment are increasingly connected with sustainability objectives.

Zahedi et al. [8] reviewed Digital Twin technologies in the sustainable construction industry and discussed the relationship between digitalization, environmental performance and sustainable construction practices.

Piras et al. [4] also reviewed the technological enablers required for Digital Twin applications in the built environment, highlighting the importance of connectivity, sensor technologies and integrated information systems.

These studies indicate that sustainable Digital Twin systems should combine physical

**III. PROPOSED BIM-INTEGRATED DIGITAL TWIN FRAMEWORK**

The proposed framework is designed to establish a continuous connection between physical building infrastructure and its digital representation.

The framework uses BIM as the central source of building component information and integrates it with IoT-based monitoring systems to support operational updates.

The proposed system consists of physical building infrastructure, sensor acquisition, communication, information integration, Digital Twin visualization, analytical processing and decision support.

**A. Physical Building Infrastructure**

The physical building represents the real environment in which the monitoring system operates.

It includes structural elements, HVAC equipment, electrical systems, lighting installations, water distribution systems, elevators and other building services.

Each relevant physical component should have a corresponding digital identity within the BIM information model.

This allows operational measurements to be connected to the appropriate building space, component or equipment.

**B. BIM Information Model**

The BIM information model provides the structured digital representation of the building.

It includes architectural information, structural components, mechanical systems, electrical installations and relevant facility information.

The BIM model should contain sufficient component identifiers and technical attributes to support integration with operational monitoring systems.

Building spaces, equipment and structural components should be organized consistently to enable reliable association between physical monitoring data and digital building information.

The model may also contain equipment specifications, installation details, maintenance records and asset identification information.

**C. IoT Sensor Acquisition**

The sensor acquisition module collects operational information from the physical building.

Different types of sensors are considered based on the monitoring objectives.

Temperature and humidity sensors provide information about indoor environmental conditions. Occupancy sensors support the identification of building utilization patterns.

Energy meters monitor electricity consumption across building systems and equipment. Water flow sensors support resource management and leakage identification.

Vibration sensors and strain sensors can provide relevant information for structural health monitoring.

The selection and installation of sensors should be based on building function, monitoring requirements, environmental conditions and maintenance accessibility.

**D. Communication and Data Transmission**

The communication layer transfers sensor information to the Digital Twin platform.

Depending on the building environment, data may be transferred through Wi-Fi, Ethernet, Zigbee, Bluetooth Low Energy or other suitable communication technologies.

Protocols such as MQTT and BACnet may be considered for different monitoring and building automation applications.

The communication architecture should support reliable data transmission, device identification, time synchronization and secure communication.

A gateway may be used to aggregate sensor information before transmitting it to a centralized platform.

**E. Data Integration and Synchronization**

The data integration module connects sensor measurements with the corresponding BIM components.

Each monitoring device should be associated with a unique sensor identifier and the relevant building asset identifier.

Incoming data should include measurement timestamps, device information, measurement units and relevant quality indicators.

A synchronization mechanism is required to update the digital representation according to the availability and frequency of incoming physical measurements.

Different building systems may generate information at different sampling frequencies. Therefore, the integration platform should support asynchronous data collection and appropriate timestamp management.

The BIM model should retain its structured asset information while the Digital Twin platform manages operational changes and current sensor observations.

**F. Digital Twin Visualization**

The visualization module provides an interactive representation of building conditions.

Users should be able to navigate building spaces and identify equipment associated with abnormal operational conditions.

Energy consumption, indoor environmental observations and equipment conditions can be associated with the corresponding digital components.

Visual indicators can help facility managers distinguish normal operating conditions from maintenance warnings and abnormal observations.

Historical sensor information should also be available to support comparison between current and previous operational periods.

**G. Analytics and Decision Support**

The analytics module processes operational information to identify abnormal patterns and support maintenance planning.

Rule-based monitoring can be used to identify readings outside predefined operating ranges.

Statistical analysis can support the identification of unusual energy consumption patterns.

Machine learning models may be used to analyse equipment performance and predict potential maintenance requirements when sufficient historical data are available.

Decision-support functions may recommend additional inspections, equipment servicing or operational adjustments.

Human verification should remain part of the decision-making process, particularly for structural safety and critical building systems.

## IV. REAL-TIME MONITORING APPLICATIONS

The proposed BIM-integrated Digital Twin framework supports multiple building monitoring applications.

### A. Energy Consumption Monitoring

Energy monitoring is an important component of sustainable building management.

Modern buildings consume electricity through lighting, HVAC systems, elevators, pumps, electronic equipment and other operational facilities.

Energy meters and smart monitoring devices can provide information about energy utilization at building, floor, zone or equipment levels.

The Digital Twin platform can associate these measurements with corresponding BIM components.

This enables facility managers to examine energy consumption patterns and identify systems that operate inefficiently.

For example, HVAC equipment operating outside required occupancy periods may increase unnecessary electricity consumption.

The integrated platform can help identify such operational patterns and provide information for improving system scheduling.

Historical energy data can also support comparison across different operating periods.

### B. Indoor Environmental Quality Monitoring

Indoor environmental quality directly influences occupant comfort and building usability.

Important monitoring parameters include temperature, relative humidity, carbon dioxide concentration, particulate matter and ventilation conditions.

Environmental sensors distributed across building zones can transmit measurements to the monitoring platform.

The Digital Twin can display environmental information according to room and floor locations.

This allows facility managers to identify zones with unusual indoor conditions and examine potential relationships with HVAC operation and occupancy patterns.

The collected information can support ventilation management, comfort evaluation and environmental quality improvement.

However, sensor-based measurements should be calibrated and interpreted according to relevant indoor environmental requirements.

### C. Structural Health Monitoring

Structural health monitoring provides information about the condition and performance of structural building components.

Vibration sensors, strain sensors, displacement monitoring systems and temperature sensors may be installed at relevant structural locations.

The collected measurements can be associated with structural components represented within the BIM model.

Engineers can examine monitoring information and identify changes that may require additional inspection.

The Digital Twin can also support the historical visualization of structural observations.

This capability is particularly relevant for large buildings, public infrastructure and structures exposed to changing environmental conditions.

The framework should not independently determine structural safety without validated engineering analysis and professional assessment.

### D. Water Consumption and Leakage Monitoring

Water management is an important consideration in sustainable infrastructure.

Water meters and flow sensors can be integrated into building distribution systems to collect consumption information.

The BIM environment can provide information about water pipes, distribution zones, storage tanks and connected equipment.

When sensor readings indicate unusual water usage, the Digital Twin platform can help identify the relevant system and support further investigation.

Leakage monitoring can help reduce water losses and avoid damage to building materials and electrical systems.

Historical consumption records can also support demand monitoring and resource management.

## V. SYSTEM IMPLEMENTATION METHODOLOGY

The implementation of the proposed framework requires coordinated development of the BIM model, sensor network, communication platform, data management environment and Digital Twin interface.

### A. Building Information Model Preparation

The first stage involves developing or preparing the BIM model of the selected building.

The model should contain relevant architectural, structural and building services information.

Component identification should be consistent so that physical equipment and monitoring devices can be associated with their digital representations.

Information such as equipment identifiers, locations, technical properties and maintenance details should be included where available.

**B. Sensor Selection and Deployment**

The sensor deployment process should begin with defining the monitoring requirements.

Energy consumption monitoring requires appropriate electrical meters and sub-metering arrangements.

Indoor environmental monitoring requires sensors for temperature, humidity, air quality and other selected environmental parameters.

Structural monitoring may require vibration, strain or displacement sensing systems.

Water monitoring requires flow meters or suitable leakage detection devices.

Sensor installation locations should be selected based on building layout, monitoring objectives and system accessibility.

**C. Communication Integration**

The sensors should be connected to an appropriate communication gateway or building network.

The communication configuration should support reliable transmission, device identification and synchronized time information.

The gateway may perform initial filtering and data validation before forwarding information to the central platform.

Network failures and temporary communication interruptions should be considered during implementation.

**D. Digital Twin Platform Development**

The Digital Twin platform should provide a connection between the BIM information model and operational sensor data.

The platform should support three-dimensional building visualization, asset identification, data history and operational monitoring.

The sensor information should be associated with corresponding BIM components through stable identifiers.

Users should be able to retrieve historical records and examine current building conditions.

The platform may use cloud-based services or locally hosted computing infrastructure depending on security, cost and operational requirements.

**E. Data Analytics Integration**

The analytics component should process incoming sensor information and identify operational conditions requiring attention.

Rule-based monitoring can provide alerts for values outside predefined thresholds.

Historical analysis can identify repeated equipment abnormalities or unusual energy consumption patterns.

Machine learning methods may be introduced for anomaly detection and predictive maintenance.

The choice of model should depend on data availability, building system characteristics and the required level of interpretability.

## VI. PERFORMANCE EVALUATION AND DISCUSSION

The proposed framework requires evaluation across data integration, monitoring performance, system reliability and sustainability-related functionality.

Since the proposed work is presented as a conceptual framework, no experimental performance values or measured energy savings are claimed.

### A. Data Synchronization Performance

Data synchronization is a fundamental requirement for a functional Digital Twin.

The digital representation should receive measurements from the physical environment and associate them with the correct building component.

Evaluation should examine the delay between sensor measurement and its availability in the Digital Twin interface.

The system should also be tested for missing records, delayed transmissions, duplicated measurements and incorrect asset associations.

Different monitoring parameters may require different update frequencies. For example, vibration monitoring may require more frequent sampling than periodic energy reporting.

Therefore, synchronization requirements should be established according to the operational purpose of each sensor.

### B. Monitoring Reliability

Monitoring reliability refers to the ability of the system to provide accurate and consistent operational information.

Sensor calibration, device health and communication reliability are important factors affecting monitoring quality.

The system should identify unavailable devices and incomplete measurement records.

Data validation procedures should be used to detect unusual sensor readings and communication errors.

Reliable monitoring is necessary because incorrect measurements may generate unnecessary maintenance alerts or hide genuine operational problems.

**C. Energy Management Performance**

Energy management performance can be examined using operational consumption records, system operating schedules and equipment-level monitoring.

The Digital Twin should support comparison between different building zones and equipment systems.

Facility managers can use these observations to identify unnecessary operating periods and investigate potential energy efficiency improvements.

The impact of operational changes should be assessed using actual energy consumption records while accounting for changes in occupancy, weather and building usage.

**D. Structural Monitoring Performance**

Structural monitoring performance should be evaluated based on sensor reliability, data availability and the ability to identify relevant changes in structural observations.

The system should maintain the relationship between monitoring devices and their corresponding structural components.

Historical monitoring information should be available for engineering examination.

Potential structural abnormalities should be verified through appropriate engineering assessment before any maintenance or safety decision is taken.

**E. Predictive Maintenance Performance**

Predictive maintenance can improve the management of building equipment by using historical operational information to identify potential deterioration.

The system may analyse changes in temperature, vibration, pressure, operating cycles and equipment performance.

The effectiveness of predictive maintenance should be evaluated using fault identification quality, false alert frequency and the time available for maintenance intervention.

Machine learning models should be trained using representative and properly labelled historical equipment data.

The system should not claim predictive accuracy without documented testing and validation.

**F. Interoperability and Scalability**

Interoperability is important because buildings commonly contain equipment from different manufacturers and operational systems.

The BIM model, sensor network, building management system and analytics platform should exchange information using suitable data formats and communication interfaces.

Open information exchange mechanisms can reduce dependency on specific software

Scalability should be evaluated through increasing sensor counts, additional building zones and expanded monitoring requirements.

### G. Overall Discussion

The proposed framework establishes an integrated approach to building information management and real-time operational monitoring.

BIM provides structured building information, while IoT sensors provide current operational observations. The Digital Twin platform connects these sources to create a continuously updated digital environment.

The framework also extends building monitoring beyond energy management by including indoor environmental quality, water utilization, structural health and equipment condition.

These capabilities are important because sustainable building management requires consideration of multiple interacting systems rather than focusing exclusively on electricity consumption.

## VII. SUSTAINABILITY IMPLICATIONS

Sustainability is a central consideration in the proposed Digital Twin framework.

The continuous collection and analysis of building operational information can support efficient resource management and improve the visibility of environmental performance.

### A. Energy Efficiency

Energy monitoring can help identify equipment operating outside required schedules and building zones with unusual consumption patterns.

The Digital Twin may support analysis of HVAC operation, lighting utilization and electrical equipment performance.

Operational adjustments can then be examined using historical and current energy information.

Actual energy savings must be verified using measured consumption data under comparable operating conditions.

### B. Water Resource Management

Water monitoring can support efficient management of building distribution systems.

Flow monitoring and consumption analysis can help identify potential leakage and unusual usage patterns.

The association between water distribution information and BIM components can help maintenance personnel locate the relevant system components.

### C. Indoor Environmental Sustainability

Indoor environmental monitoring provides information regarding temperature, humidity, air quality and ventilation conditions.

These observations can help balance occupant comfort and building energy performance.

The Digital Twin can provide a common environment for examining the relationship between indoor conditions, occupancy and building system operation.

### D. Equipment Lifecycle Management

Predictive maintenance and equipment condition monitoring can support better maintenance planning.

Early identification of abnormal operating conditions may help reduce unexpected equipment failures and avoid unnecessary replacement activities.

Maintenance records connected with BIM asset information can also improve the continuity of facility information.

## VIII. IMPLEMENTATION CHALLENGES AND LIMITATIONS

### A. Data Interoperability

The integration of BIM models, IoT devices and building management systems may be complicated by different data formats and software environments.

Information exchange should be supported through appropriate application programming interfaces, structured data models and consistent component identifiers.

Open data standards and agreed information management procedures can help reduce integration difficulties.

### B. Data Quality and Reliability

Sensor information may contain missing values, unusual readings, communication delays and calibration errors.

The Digital Twin platform should incorporate data validation and monitoring procedures to identify unreliable measurements.

The reliability of the digital representation depends on the quality of the information received from the physical building.

### C. Initial Implementation Cost

The deployment of sensors, communication infrastructure, computing platforms and Digital Twin software may require significant initial investment.

Existing buildings may also require additional work to establish accurate digital models and connect previously independent building systems.

Implementation planning should therefore consider monitoring priorities and expected operational benefits.

### D. Cybersecurity and Privacy

The integration of IoT devices and building information platforms creates cybersecurity requirements.

Unauthorized access to sensor networks or building management systems may affect the confidentiality and reliability of operational information.

Secure communication, device authentication, access controls, network monitoring and regular software maintenance should be considered.

Occupancy-related monitoring should also follow appropriate privacy and data protection requirements.

**E. Existing Building Integration**

Older buildings may not contain complete BIM information or digital equipment records.

In such cases, reality capture, equipment inspections and asset information collection may be required before establishing the Digital Twin.

Cespedes-Cubides and Jradi [3] also identified the limitations associated with existing buildings that lack comprehensive digital information and reliable data acquisition systems.

## IX. FUTURE RESEARCH DIRECTIONS

Future research can extend the proposed framework in several directions.

A. Artificial Intelligence-Based Predictive Analytics: Machine learning and deep learning techniques can be investigated for predicting equipment deterioration, abnormal energy consumption and potential maintenance requirements.

B. Advanced Structural Health Monitoring: The integration of advanced sensing systems and structural analysis models can improve the assessment of building structural performance.

C. Automated Building Performance Optimization: Future systems can examine automated adjustments to HVAC, lighting and other building services while maintaining occupant comfort and operational constraints.

D. BIM-GIS Integration: Connecting BIM-based Digital Twins with Geographic Information Systems can support monitoring of building assets within larger campus and urban infrastructure environments.

E. Federated Digital Twin Systems: Future studies may investigate the integration of multiple building Digital Twins to support district-level energy and infrastructure management.

F. Cybersecurity and Trusted Data Exchange: Additional research is required to improve secure data sharing, sensor authentication, access governance and information integrity.

G. Long-Term Experimental Validation: The proposed framework should be tested in operational buildings over extended monitoring periods to examine reliability, scalability and measurable sustainability outcomes.

## X. CONCLUSION

This paper presented a BIM-integrated Digital Twin framework for real-time monitoring of sustainable building infrastructure. The proposed approach combines building information models, IoT-enabled sensing systems, communication technologies, cloud-based data management and analytical services to establish a connected representation of physical building assets.

The framework considers important operational monitoring applications, including energy consumption, indoor environmental quality, structural health, water utilization, equipment performance and occupancy management.

BIM provides the structured information foundation required to identify building spaces, components and equipment. IoT sensors provide operational measurements, while the Digital Twin platform connects these observations with their corresponding digital representations.

The proposed framework also supports anomaly identification, predictive maintenance and building performance assessment through the integration of analytical methods.

The literature indicates that BIM-integrated Digital Twin technologies have considerable potential for sustainable building operation and maintenance. However, successful implementation depends on reliable data acquisition, appropriate information synchronization, interoperability, cybersecurity and continuous model maintenance.

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