buildingSMART International (2022)
372-PROFESSIONAL Professional Research using openBIM

GdVbkbeW

Secure openCDE with Blockchain for HKUST Campus-wide Digital Twin with openBIM and openGIS Applications

Entrant details

Role or Job Title on the Project	Professor and Project Manager of HKUST Digital Twin

Employer

The Hong Kong University of Science and Technology

Employer Role	Academic or Research Institution
Are you or your employer a member of buildingSMART?	No

Entry details

Entry Details

By checking this box I understand and acknowledge that this awards program is to assess information about openBIM, and that openBIM is not only about the use of solutions. openBIM is about setting up an environment where every party in a team can work in the optimal way ("how they prefer") without putting limitations on others. It is about freedom to take control over your data and workflows, while keeping that freedom for others as well. Full use of open standards is not mandatory for this mission.	✓

Website | https://digitaltwin.hkust.edu.hk

Location

The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

Submitting Party and Stakeholder Logos (compiled into one .ppt/pptx file for upload)

PPTX Project_and_Stakeholder_L... (324 KiB download)

Entry Description

The Hong Kong University of Science and Technology (HKUST) carries a vision of creating a digital twin, which digitizes the entire campus with over 60 buildings covering a total floor area of about 500,000 m2 with different facility systems integrated into a single hub. This will significantly enhance facility management (FM) like engineering analyses, operation management and maintenance. Diverse data sources are available, including building information modeling (BIM), geographic information system (GIS), Internet of Things (IoT) and building management system (BMS). Yet, these data sources are traditionally scattered among different databases or represented in different schemas, making FM process tedious and time-consuming in matching diverse data sources. Regarding data storage and sharing among different parties, the existing common data environments (CDEs) lack data security, such that sensitive FM data may be leaked or accessed by unpermitted parties.

Our research achievements are four-fold. (1) Considering openBIM, a IFC data model is proposed for seamless BIM-GIS integration, capturing a realistic 3D topology of the entire HKUST in rich details. IFC schema is seamlessly interoperable with Esri ArcGIS platform, where an online dashboard is developed for web-based model interaction and query. (2) The BIM-GIS model is then integrated with distributed IoT data based on openGIS, where an extended CityGML model is proposed to incorporate real-time IoT data, which are parsed from other HKUST portals with Python API. A mobile app is developed for general public to interactively query the operational performance, like indoor air qualities. (3) The BMS data are also integrated into the BIM-GIS model, including air-conditioning system performance. With an open ontology called Brick schema, the functional interaction between BMS and surrounding geometry is effectively captured. (4) A secure openCDE is developed with a blockchain model, which encrypts FM data and authenticates a staff's permission level before granting access privileges. Data sharing are guaranteed high integrity, authentication and transparency among different FM parties.

What stage of completion is the entry content representing? | Substantial Completion and Beta Testing Stage

Stakeholder Statements

Prof. Hong K. LO, Director of HKUST GREAT Smart Cities Institute and former Department Head in Civil and Environmental Engineering at HKUST, has been supervising the HKUST smart campus development and evaluated the merit of this entry as follows:

"Prof. Jack Cheng leads the Digital Twin (D.T.) development for HKUST. He has done a fantastic job, making HKUST the first university to have a complete D.T. for facility management and data display. I am strongly satisfied with the works performed by the HKUST Digital Twin team. I strongly agreed that the team had demonstrated the required level of competency in this project, regarding the following 5 aspects, (1) BIM initiation, (2) BIM software and technologies, (3) BIM uses and processes, (4) digital information management, collaboration and integration, (5) communication skills."

Upload a 2 minute video to show the scope of the entry.

MP4 HKUST_Digital_Twin_Blockc... (15.2 MiB download)

Problem Statement

Facility management (FM) in the operation and maintenance stage is crucial for infrastructure spaces, such as buildings of universities and shopping malls that serve a large group of occupants. With people usage taken into account, FM practices should ensure smooth functioning of the facility components, in order to bring occupants higher levels of comfort and enjoyment. More specifically, FM practices should enable effective queries of the required facility information, which subsequently support the performance analyses by managers, maintenance works by staff or behavioral decision-making by occupants. To this end, the routine process of FM involves diversified information, including spatial layout plans, historical maintenance records and real-time sensing data. FM activities tend to require information from multiple data sources, i.e., building information modeling (BIM), building management systems (BMS) and Internet of Things (IoT) networks. However, these data sources are traditionally scattered among different databases or systems. These kinds of data from different sources are usually in different schemas, which hinder data interoperability. It is time- and effort-consuming work for FM managers may need to tediously match or correlate different data sources, in order to query and integrate information from these heterogeneous data sources to support FM activities. Hence, a workflow based on uniform data schema and platform is needed to integrate different data sources for more effective FM practices.

One potential solution is to digitize an as-built environment as digital models, and associate each component with its actual condition such that the real-world environment is synchronized. Such an approach is defined as digital twin, i.e. to create a digital model of a physical object, such that the actual conditions of the real-world components are reconstructed digitally. Through continual and dynamic data exchange between the physical and digital environments, the two versions of an object can synchronize themselves with real-time data updates and monitoring. Several technologies constitute the basic ingredients for realizing digital twin: (1) BIM features a process to store and manage facility information based on a digital representation, which is intuitively a platform to gather the geometric and semantic attributes of facility spaces and components (e.g. floors, walls and rooms). (2) IoT generally denotes a distributed network of remote sensing devices to capture environmental conditions (e.g. indoor air qualities (IAQ), human occupancy). In addition, building operation typically involves the management of heating, ventilation, and air conditioning (HVAC) systems, which constitute a sub-field of BMS that is essential to be modeled in a digital twin. Yet, current methodologies still lack unified data schema or workflow for integrating different data sources. This research aims to address four problems as follows:

(1) Integrating multiple BIM sub-models of an area into a single platform:
BIM focuses on fairly detailed components inside an individual building, while not capturing the larger-scale topological information. On the other hand, another technology named Geographic Information System (GIS) stores the geospatial data and their topological relation in a wide area. The data schemas between BIM and GIS notably differ from each other. Therefore, seamlessly integrating BIM and GIS data without information loss is crucial.

(2) Integrating IoT data with BIM-GIS to support facility condition monitoring:
While BIM/GIS stores a digital model of the facility, IoT data from remote sensors are isolated and scattered. The locations of individual IoT device should be identified in the digital model and then associate it with the device-specific measurements from the correct device. To effectively manage distributed IoT sensors, openGIS standard is a potential solution to exchange IoT data with BIM/GIS platforms. Combining IoT with BIM/GIS facilitates different FM applications, including IAQ and pedestrian crowd monitoring.

(3) Integrating BMS information with BIM data to support HVAC system monitoring:
A uniform schema is needed to support the integration of data from different sources, including BIM, BMS and IoT. Hence, openBIM standard can potentially facilitate the data integration for FM applications like IAQ assessment. The digital twin platform can serve as an API to access the FM information. As the digital twin contains accurate geometric, semantic and location information of the building and facility data, the information and sensor data can be used to support IAQ assessment of the building. Hence, a methodology is needed to integrate BIM and BMS data.

(4) Managing all the facility data securely for FM practices:
Upon the data integration among BIM, GIS, IoT and BMS, a methodology is needed to ensure secure data management. Currently, common data environment (CDE) is used to store and share data among different parties, e.g. facility maintenance records of buildings. However, the existing CDEs are lacking in data security which may not be applicable for digital twin. A digital twin generates large amounts of data at frequent intervals which gets constantly updated, In the FM process, historical data is crucial for multiple purposes such as tracking the lifecycle of the FM processes and official audits, thus should be kept with high integrity and authenticity upon sharing among multiple end-users. Hence, a method is needed to ensure data security and authenticity upon sharing among multiple end-users.

Previous efforts and limitations

Different data standards for BIM are available, such as Industry Foundation Classes (IFC) for general usage and Construction Operations Building information exchange (COBie) particularly serves FM processes. However, the integration of BIM data with GIS platforms still suffers from data loss due to inconsistent attribute definition. This hinders the union of multiple BIM models in GIS platforms, where topological data like landscapes are readily modeled. In addition, individual BIM model contains highly detailed components and information, which will imply high computational load when visualizing a combination of many BIM models, possibly leading to unfavorable user experience upon data visualization.

Existing data schema cannot fully address the information requirement of the FM domain. Several data tools can represent and manage building information and performance data. The ontology method is used for metadata and standardized representation of data in building sections. Such tools include Brick Schema, Project Haystack, GreenButton, etc. Brick Schema, as a representative ontology method among these tools, can facilitate the organization of BIM, FM, and IoT data as a uniform schema to integrate different data sources for effective FM process. However, only up to a few hundred building have Brick models at the time and there is still lack of in-situ practices of Brick Schema. Besides, how to integrate the schema into the digital twin platform effectively is another problem to be solved. Such data integration is essential to support FM applications like IAQ assessment and monitoring, since it is often not possible to take measurements or install sensors across an entire floor due to concerns about occupant privacy. Limited obtainable field measurements hinder overall IAQ assessment and monitoring and it becomes difficult for building managers to identify poor ventilated areas. To support a healthy indoor environment, a methodology is needed to integrate BIM and BMS data for more accurate IAQ assessment. In addition, there have been several representations published, such as Semantic Sensor Networks (SSN) and OGC Sensor Web Enablement suite for managing IoT data, while there still lacks a universal data representation especially when integrated with BIM/GIS.

Traditionally, data for facility management is gathered and dispersed from different sources such as Electronic Document Management Systems (EDMS) and Building Automation Systems (BAS). It is well established that BIM models are essential for integration between FM and maintenance systems to synchronize information and avoid errors. For example, for maintenance of HVAC systems such as chillers, integrated and synchronized data such as (i) minimum acceptable or maximum allowable readings of real-time monitored data from IoT sensors, (ii) historical records such as inspection frequency from FM database, and (iii) location information such as the name of the space/floor from BIM models is required. A digital twin which integrates BIM models and IoT networks to represent a physical building in real-time is a solution to the requirements of FM. However, the existing CDEs are lacking in data security and data integration crucial to facility management processes. A digital twin generates large amounts of data at frequent intervals which gets constantly updated, thereby overwriting historical data. However, in the FM process, historical data is crucial for multiple purposes such as tracking the lifecycle of the FM processes and official audits. In addition, the authenticity of those historical records is also very important considering frequent data sharing by multiple end-users over the internet and the use of cloud technologies. Therefore, an openCDE is needed to capture and track information from openBIM models using the IFC format, IoT sensors and documents.

Research method

1) BIM-GIS data integration based on openBIM:
To create a digital twin of an environment, its geometric and semantic attributes are modeled to reconstruct a realistic 3D model. In particular, a workflow is developed to realize BIM-GIS data integration, such that a large-scale digital twin is generated to support both microscopic analyses and macroscopic management. To this end, openBIM data schema can enhance data interoperability and avoid data loss between BIM and GIS platforms. Hence, a IFC data model is proposed to govern the attribute modeling in BIM, as well as the data transfer to GIS. Figure A1 summarizes the IFC attributes being modeled. Several fine-grained attributes are surveyed in order to support certain applications, e.g. the dimensions of doors and windows for air flow analyses, dimensions of stairs for walkability analyses. Based on the proposed IFC schema, individual buildings/spaces of an area are constructed. A methodology is also proposed to reduce the file size, by combining architecture components while keeping room masses separate, minimizing the graphical rendering loads for smoother visualization. After creating individual BIM sub-models, they are exported to IFC files and imported to a GIS platform, along with the landscape model of the surrounding topography. Each BIM sub-model is geo-referenced to the appropriate location in GIS environment, such that the overall topology is reconstructed. The use of openBIM standard guarantees data interoperability during the BIM-GIS data integration, enabling a consistent data mapping to preserve the BIM attributes. The BIM-GIS model integrates various data sources (including buildings, landscapes and topology) into a single hub, which is then published online to allow information query or management by different parties.

2) BIM-GIS-IoT data integration based on openGIS:
The BIM-GIS model serves as the backbone of the digital twin, into which IoT data are integrated in order to realize different applications of facility performance monitoring. IoT data are solicited from a distributed network of devices like sensors (more generically, facilities defined as POIs). Hence, a workflow based on openGIS is proposed to integrate IoT data into the BIM-GIS model. In particular, a data model based on CityGML is put forward to formalize the necessary attributes related to IoT data being integrated. Figure A2 summarizes the CityGML attributes, with an extended schema proposed for the IoT components / POIs in the digital twin, e.g. temperature, humidity and CO2 level from IAQ sensors, pedestrian counts from WIFI nodes, operational statuses of printers and water fountains. Importantly, the location of individual POI in the BIM-GIS model is stored to capture the spatial distribution of all the POIs. Furthermore, the statuses are captured in a time-series manner, i.e. storing a series of measurements over time indexed by the datetime attribute, enabling richer spatiotemporal analyses and thus facilitating the planning process. The use of openGIS standard guarantees a smooth data exchange process when integrating IoT measurements into the BIM-GIS platform. With the distributed IoT data gathered in a single holistic model published online, the operational conditions of the POIs are visualized (e.g. in web dashboard

or mobile apps). The information will greatly support the decision-making of occupants (e.g. walking path selection) and facility managers (e.g. IAQ monitoring).

3) BIM-GIS-BMS data integration based on open ontology:
In addition, a methodology is proposed to effectively integrate the BIM-GIS model with the BMS data, e.g. HVAC information. This integration will facilitate the BMS information query and thus different kinds of building performance analytics. Hence, a workflow based on openBIM and open ontology is developed to integrate BIM-GIS and BMS data. In particular, a data model based on the Brick schema is proposed to formalize the semantic descriptions of building assets and their relationships. Figure A3 summarizes the overall workflow of generating a Brick ontology model by integrating the openBIM and BMS data. While IFC files provide the spatial information of BIM models, BMS platforms (e.g. Delta, Honeywell) provide the HVAC information such as air handing units (AHUs) and variable air volumes (VAVs). These two data sources are processed and converted into Terse RDF Triple Language (Turtle) files, subsequently with a Brick model generated. The Brick model summarizes the hierarchical relationships between the HVAC components (e.g. AHUs, VAVs, zones and points). By utilizing openBIM standard upon BIM-GIS-BMS integration, the spatial information of building spaces can be extracted and effectively combined with BMS data. Hence, the operational statuses like supply air temperature can be monitored, which can enable energy performance evaluation or predictive maintenance of HVAC components.

4) BIM-GIS-Blockchain integration for secure data management in an openCDE:
With various data sources integrated into a single platform, different parties of the area will participate in managing or extracting the data, for their routine FM processes or certain analyses. Such a practice demands a methodology to enable efficient data sharing, while ensure security and integrity of the data being hosted. Hence, an openCDE framework based on blockchain is developed and integrated with the BIM-GIS platform. Figure A4 shows the blockchain-enabled openCDE framework for securely integrating FM-related information to facilitate FM processes. The blockchain data model provides a unified and data-neutral record to track who did what and when throughout the lifecycle of a facility. The framework consists of two layers – (1) a blockchain layer for integrating graphical and non-graphical information from different data sources in a secure manner and (2) a shared repository for the storage and graphical and non-graphical information. The blockchain layer provides the security of irreversibility and prevents the information from being over-written and provides a method for viewing/auditing information as required by FM processes. With the developed openCDE framework based on blockchain, various data sources involved in the digital twin are gathered into a single source, being secured while effectively shared among different parties. Such a framework facilitates the data management and usage by facility managers.

Findings/Validation

1) BIM-GIS data integration based on openBIM:
The Hong Kong University of Science and Technology (HKUST) campus was used as the testbed, with a research project entitled “Digital Twin for HKUST Campus”. 3D BIM models were created for the whole campus based mainly on CAD drawings and field survey supported by laser scanning technology. Eventually, the entired HKUST campus were modeled in Autodesk Revit, including the academic buildings, student/staff halls and the landscape. The BIM reconstruction totally covered more than 60 buildings, 20,000 rooms and floor area 500,000 m2. The BIM models were validated by field audit and laser scanning. Point cloud data were scanned and imported to Revit, and then aligned with the created BIM models for consistency verification, e.g. identifying any deviated placement of walls or columns. After creating individual BIM models, the sub-models and landscape were imported to Esri ArcGIS Pro via IFC files, and each sub-model was geo-referenced to its location on the landscape. ArcGIS Pro effectively supports IFC data interoperability with a BIM-GIS data mapping scheme (e.g. BIM categories to GIS feature classes, BIM families/types to GIS attribute values). Based on openBIM standard, the BIM attributes were well preserved upon integrating into GIS. Figure A5 shows the web dashboard developed in ArcGIS Online for interacting with the BIM-GIS model (e.g. component attribute query).

2) BIM-GIS-IoT data integration based on openGIS:
Based on the proposed CityGML data model, different POI data sources were effectively extracted and integrated into the BIM-GIS model. Facility POIs like printers and water fountains were located in the 3D BIM-GIS model and associated with the required attributes. In addition, IoT data obtained from other HKUST databases were integrated into the BIM-GIS model. These include the real-time pedestrian counts from the HKUST Pulse system based on WIFI localization, the IAQ measurements from the Smart Campus Air Network (SCAN) collecting the real-time temperature, humidity, PM2.5/10 and CO2 levels at different locations. An ArcGIS Online interface was made to visualize the operational conditions of POIs and pedestrian counts at different locations. Figure A6 shows the interactive mobile apps developed for querying real-time IAQ at a user-specified room. For smoother user experience in mobile devices, the BIM models were down-sized and exported to the Unity engine, with room attributes well preserved.

Based on openBIM and openGIS standards, the IoT/POI data from other systems were effectively incorporated into the BIM-GIS model to support decision-making of different parties. Figure A7 illustrates a case study of emergency evacuation. The walkable network was generated by processing the geometry of the openBIM-GIS model. IoT sensors were used to identify crowd density, temperature and CO2 (indicators of fire) at different locations. An augmented reality (AR) mobile app was developed to guide users towards the most walkable path avoiding the crowd and fire. With BIM-GIS-IoT data integration, occupants can obtain immediate feedback regarding the current crowd condition to make an informed choice of walking path or dining place, building managers can monitor IAQ at different locations and adjust HVAC system settings accordingly.

3) BIM-GIS-BMS data integration based on open ontology:
Based on the proposed Brick ontology schema, BMS data like HVAC information were smoothly enriched by the spatial information of the BIM-GIS model. HVAC information from BMS platforms including Delta and Honeywell were extracted, while spatial information were extracted from BIM models based on IFC files to ensure data interoperability under openBIM standard. Python programming was implemented to automatically process these two data sources, eventually generating a Brick model efficiently. The resulted Brick model systematically captured the hierarchical relationships between HVAC components, e.g. a VAV consisting of a supply air temperature sensor and a supply air flow sensor. Figure A8 illustrates that by integrating the BIM-GIS and BMS data, the evaluation of facility performance can be greatly facilitated. For example, by modeling the operational statuses of the HVAC system, facility managers can effectively query necessary information for routine inspection of the HVAC components, or analyze their past performance trend for routine/proactive/predictive maintenance earlier before actual defect. Additional applications include IAQ assessment for evaluating occupant comfort, or energy performance analytics for optimizing energy efficiency and operational cost. The data exchange and integration with BMS platforms are greatly supported by openBIM and open ontology schema.

4) BIM-GIS-Blockchain integration for secure data management in an openCDE:
Figure A9 shows a typical facility maintenance process supported by the blockchain-enabled openCDE. The process is initiated by a FM manager. A FM staff collects building component information such as component name, dimension, and location from the relevant BIM model. The FM staff also collects information such as historical maintenance records, sensor data, and warranty and specification-related information from FM systems, IoT networks, and BIM models respectively to assess the condition of building components against pre-determined criteria. After an assessment, the FM staff assigns a maintenance request if the building component is eligible for maintenance. A blockchain record is created, linking BIM, IoT, and FM data which are uploaded to the common repository of the blockchain-enabled openCDE. Content-based cryptographic hashes of the documents uploaded to the common repository are recorded so that the authenticity of the documents and information may be verified at a later stage when required.

Subsequently, the maintenance trade, tools, and procedure are defined by the FM staff, following which a maintenance work order is generated. The work order and other relevant documents are blockchained for further processing by the FM manager. Once the work order is generated, the FM manager views the blockchain records generated in the previous steps to track the lifecycle of the maintenance process and verify the authenticity of the required information using the cryptographic references stored on the blockchain, following which he/she schedules the maintenance process. The maintenance is conducted by FM staff and the BIM model is updated which is also recorded in the blockchain to track the life cycle of BIM during the operation phase. Therefore, the blockchain-enabled openCDE acts as an irreversible point of integrated information for FM processes and provides methods to authenticate information, thereby facilitating data integration and data security.

Conclusion/Contributions/Limitations

Digital twins combine BIM-GIS and IoT networks to represent physical building models in real-time. It is specifically useful in the operations phase of a building life cycle to facilitate FM-related operations. FM operations require historical records and lifecycle tracking to support the processes themselves and official audits. However, in the digital twin historical records are often overwritten with new data at a high frequency. The existing CDEs focus on integrating information from various data sources but lack data security. Therefore, a blockchain-enabled openCDE was developed to enable data irreversibility along with data integration. A blockchain data model integrating BIM, IoT and documents was developed. A workflow demonstrating the application of the blockchain-enabled openCDE was presented.

With people usage taken into account, FM practices should ensure smooth functioning of the facility components, in order to bring occupants higher levels of comfort and enjoyment. The routine process of FM involves diversified information, including spatial layout plans, historical maintenance records and real-time sensing data. FM activities tend to require information from multiple data sources. However, these data sources are traditionally scattered among different databases or systems. These kinds of data from different sources are usually in different schemas, which hinder data interoperability. To integrate different data sources into the creation of a digital twin, methodologies are developed in four aspects: (1) BIM-GIS data integration based on openBIM where a IFC data model is proposed, (2) BIM-GIS-IoT data integration based on openGIS where an extended CityGML data model is proposed, (3) BIM-GIS-BMS data integration based on open ontology where a Brick model is put forward, and (4) BIM-GIS-Blockchain integration for secure data management where an openCDE is developed.

Example Use

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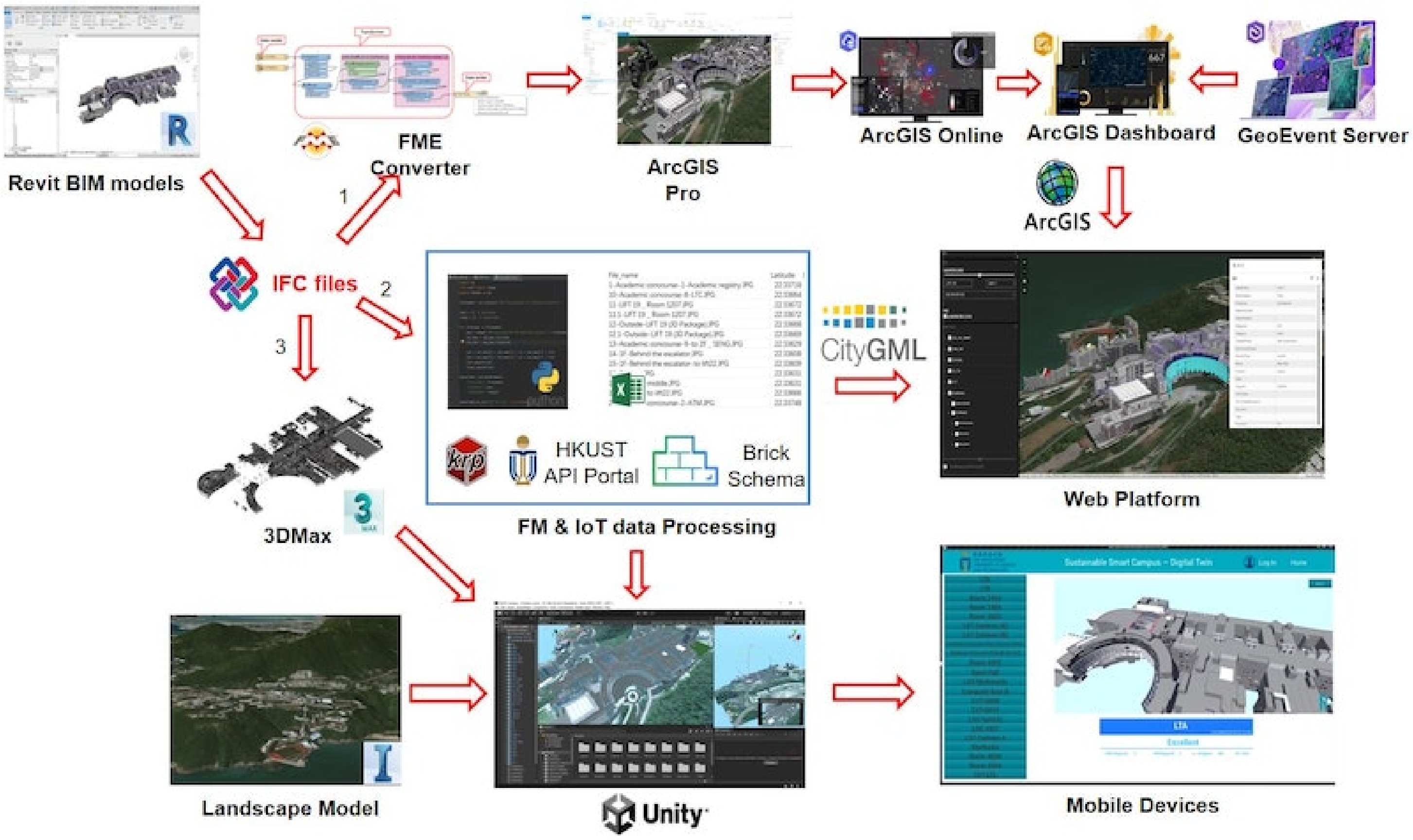
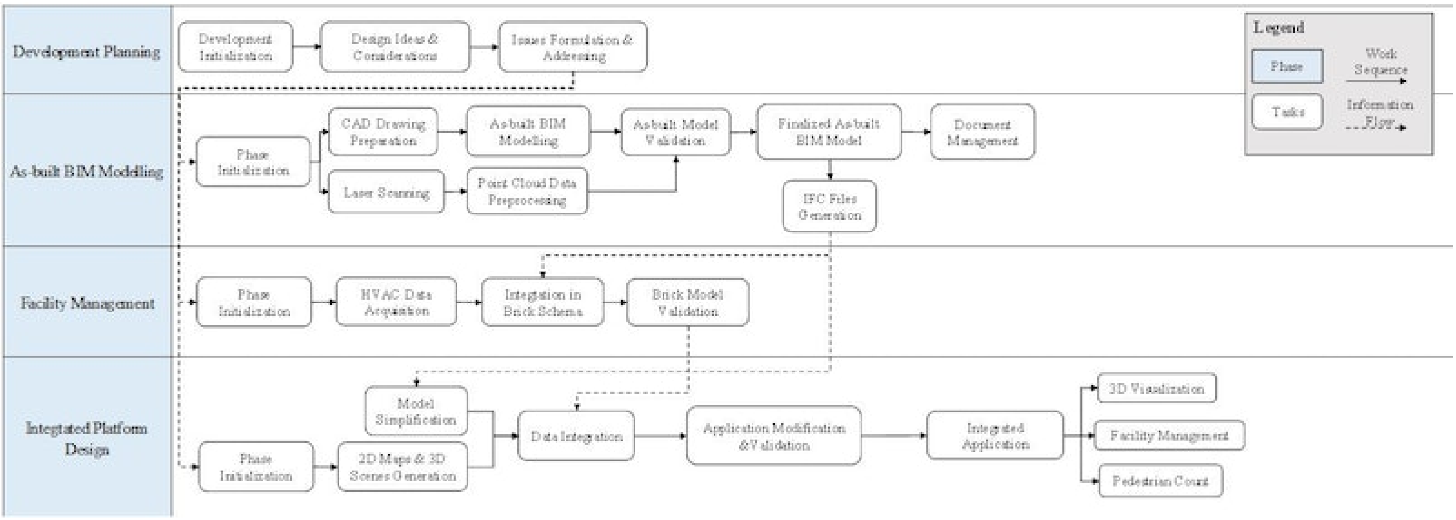
openBIM Evidence

Software Ecosystem Map



Process Maps



openBIM Data Metrics Summary

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Additional openBIM Supporting Evidence

PDF	

Supporting_Evidence.pdf (1.9 MiB download)

Lessons Learned

> Data transfer process methods should be considered carefully, especially for the large-scale BIM & GIS scenes, which always result in a large amount of data. From previous experience, it is easily told that the main academic building alone already led to a high capacity on the mobile devices. Besides, if the rendering quality is required to be high, the user operation would not be fluent, so the former application features a simple appearance and basic functionalities of IAQ data query. The lesson learned from this case is that model simplification is important for BIM applications, which could be addressed in 1) graphical model simplification and 2) semantic-guided model lightweighting. From the graphical point of view, several related studies regarding polygon reduction can be referred to for reducing the size of vertices, and view culling strategies for decreasing model size and rendering workload. However, only a few studies have explored in semantic-guided model simplification, which is also considered in our research project. Furthermore, efficient schema should also be further compared for data transfer for future work. For example, JSON schema performs with high efficiency for web-based data transmission, Brick schema enhances the data interoperability for facility management in buildings. Schema like these are recommended in future BIM applications.

"We were able to identify where we need openBIM to develop further."

> In the future, we could leverage BCF to keep track of modifications of campus buildings as there are renovation on the HKUST campus occasionally.

Upload .ifc file(s) or other technical files to support validation of the research results.	https://service.usbim.com/link/629f62748df9e611ffe5d2b5

Share any instructions for accessing the .ifc or other technical files for review.

> The ifc model uploaded to usBIM.service is accessible directly via the shared link.

Use Cases

BIM Uses were defined on the project	✓
BIM Uses formed an integral part to how the project was delivered	✓
I agree to be contacted for more information about the project BIM uses outside of this awards program.	✓

Documentation on use case(s) as a single file upload

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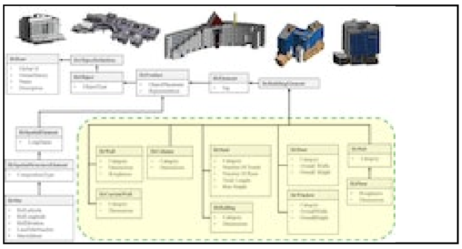

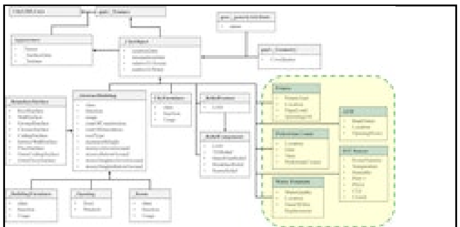

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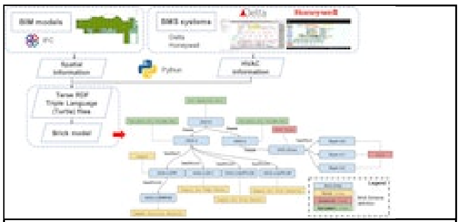

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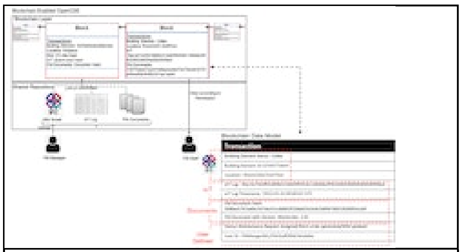

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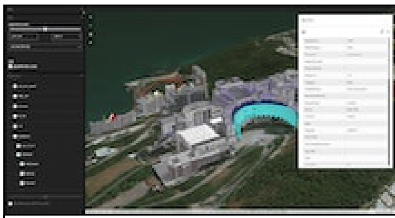

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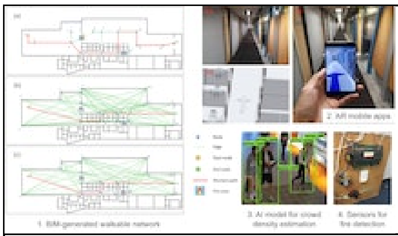

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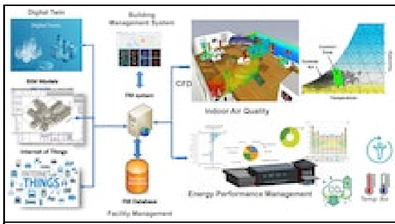

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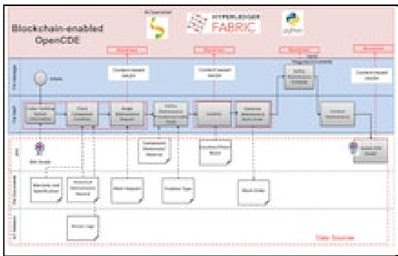

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