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RESEARCH ARTICLE

Urban Information Modeling for Smart Cities: Advancing Sustainable Infrastructure and Environmental Management in Digital Twin Applications

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ABSTRACT

Urban infrastructure and environmental management face significant challenges in supporting the integration of Smart City Digital Twins. To address these issues, Urban Information Modeling (UIM) offers a comprehensive framework that extends the principles of Building Information Modeling (BIM) by incorporating both graphical and non-graphical data. This enables a unified platform for integrating various urban elements, such as buildings, infrastructure, and public utilities, promoting more efficient and sustainable urban development. This study aims to demonstrate the UIM framework's potential to enhance resource efficiency, improve coordination in civil engineering projects, and optimize facility management processes through a case study conducted at Naresuan University. The methodology employed involves implementing the UIM framework by integrating various modeling techniques, including BIM, block models, Industry Foundation Classes (IFC), reality capture models (e.g., point clouds), 2D CAD, shapefiles, and raster datasets. Findings reveal that UIM not only improves stakeholder collaboration and urban management efficiency but also supports the sustainable construction and maintenance of urban systems. Additionally, the framework underscores UIM's critical role in fostering adaptive urban management strategies, minimizing environmental impact, and contributing to the long-term sustainability of urban development.

INTRODUCTION

Sustainable urban development is a global priority, driven by rapid urban migration. By 2050, an estimated 68% of the world's population will reside in urban areas, necessitating meticulous city management to address the resulting challenges (Department of Economic and Social Affairs of the United Nations, 2018; Pacione, 2009). This urban expansion increases the density of buildings and infrastructures, requiring effective management of resources such as buildings, roads, bridges, water supply, wastewater systems, sanitation, disaster prevention, and environmental considerations (Jacobs, 1961; Torrisi, 2009). These interconnected elements form a complex network of engineering and urban management efforts.Many countries are adopting policies to integrate information technology into urban architecture and metadata, aiming to enhance city management efficiency and promote sustainable development (Huang et al., 2021). This approach aligns with the UN's Sustainable Development Goal 11, which focuses on sustainable cities and communities (United Nations Development Programme, 2021). In Thailand, smart city development is embedded in the 20-year national strategy (2018-2037) (Thailand's National Strategy Secretariat, 2018), the National Economic and Social Development Plan No. 13 (2023-2027) (Thailand's National Economic and

Social Development Council, 2023), and the Thailand 4.0 policy (Muangrattan, 2019). However, practical implementation is hindered by the lack of integrated building data.

This lack of integration affects both public and private utilities, limiting the ability to analyze and plan effectively, thereby impeding sustainable urban development. Challenges include regulatory constraints, fragmented responsibilities among agencies, and inadequate compliance with laws. These issues contribute to environmental degradation, economic inefficiencies, social challenges, and vulnerability to disasters.

Addressing these obstacles requires enhancing data integration mechanisms, streamlining regulations, fostering stakeholder collaboration, and investing in technology infrastructure. Such efforts can enable Thailand to realize its smart city goals and advance sustainable urbanization. Building Information Modeling (BIM) plays a pivotal role in the Architecture, Engineering, and Construction (AEC) industry, driving digital transformation (Maria & Dimitar, 2019). BIM integrates intelligent models across the building lifecycle from design and construction to operation, maintenance, and eventual demolition—ensuring efficiency and sustainability at every stage.

This research extends BIM principles to Urban Information Modeling (UIM), developing a framework that integrates graphical and non-graphical data for managing utilities and public services within a unified digital city database. Historically siloed elements, such as infrastructure, water supply, sanitation, and transportation, are consolidated for collective use by city managers, government agencies, and other stakeholders. The framework aims to support smart cities by leveraging AI and IoT to enhance efficiency, livability, and sustainability.

The study involves developing a conceptual UIM framework for sustainable facility management in digital twins, testing the framework through a case study at Naresuan University, and comparing the proposed approach with traditional methods. The paper is organized into eight sections. The first two review literature and concepts of BIM, UIM, smart cities, and digital twins. Section 3 outlines the research framework, while Sections 4 and 5 detail the methodology and tools used. Section 6 presents findings from the Naresuan University case study. Finally, Sections 7 and 8 discuss the results and offer recommendations for future development.

LITERATURE REVIEW

This section discusses BIM and UIM including its definition, history, evolution, workflow, platforms, model types, levels of development, file extensions, and formats for application data exchange. It also explains the concept of UIM for Digital Twin, past research, and other relevant.

Introduction to BIM and UIM

BIM is a digital process for managing information throughout the lifecycle of buildings and other infrastructures, covering stages from design and construction to maintenance. It is not merely a 3D model; it is a tool that enables users to analyze various data such as structure, spatial arrangements, resource management, and energy consumption calculations. BIM allows stakeholders to exchange and access real-time information, enhancing decision-making efficiency and reducing potential construction risks (Eastman et al., 2011). In practical applications, BIM has been widely adopted in civil engineering and urban infrastructure projects, including infrastructure development, resource management, and environmentally friendly building designs. Several Smart City projects worldwide utilize BIM for urban governance and decision-making at different levels.

UIM is an evolution of BIM, expanding its scope to the city scale, encompassing physical data and urban infrastructure such as roads, transportation systems, buildings, land use, and energy and water networks. UIM emphasizes integrating data from multiple sources and applying it to sustainable urban development. It is known as "Digital Twin".

Digital Twin integrates cyber technology with physical models (Haag & Anderl, 2018; Qi & Tao., 2018; Tomko & Winter, 2018), whether it be building information models, infrastructure, utility systems, or other constructions. The concept of Digital Twin was first discussed around 20 years ago in the context of aviation and aerospace technology (Grieves, 2015). Today, the concept is applied across various fields, recently linking with Smart City concepts (Mohammadi & Taylor, 2017; Rezgui, 2018). Digital Twin represents an ultimate goal that may not yet be fully achievable (Howell et al., 2017; Schluse et al., 2018), focusing on intelligent and efficient data management, communication capabilities, and system sustainability. Its components include (1) physical components; (2) virtual models; and (3) connected data (Grieves, 2015).

In the Smart City context, UIM combined with Digital Twin enhances resource management and planning efficiency at an urban level. Applications include optimizing infrastructure systems, public transportation, energy management, and even predicting future community needs. The interconnected data across buildings, transportation hubs, green spaces, and other city infrastructure supports sustainable urban development. Furthermore, it allows for flexible urban planning that adapts to environmental changes efficiently (Batty et al., 2012; Vázquez Rosas et al., 2022).

Thus, BIM and UIM serve as vital tools in Smart City initiatives, reducing resource usage and minimizing waste, fostering sustainable urban growth, and aligning with the United Nations' Sustainable Development Goals (United Nations, 2015).

Process and platforms

The BIM process functions as a centralized workflow driven by multiple platforms. It involves three key components: (1) BIM Platform: This is the primary tool used to create information and parametric model components. Well-known platforms include Revit®, ArchiCAD®, OpenBuilding™ Designer, Tekla® Structures, and Vectorworks®. These platforms typically incorporate built-in libraries and interfaces to streamline workflows; (2) BIM Tools: These are supporting tools integrated within the same platform to handle tasks such as specification generation, cost estimation, scheduling, and engineering using Excel-based tools. They facilitate the processing, input, and output of data within the platform to ensure smooth operations; and (3) BIM Environment: This refers to a collection of applications, tools, platforms, servers, and workflows that support the integration of data across various processes within a project or organization. It ensures seamless connectivity and coordination between different tools and stakeholders.

There are many platforms widely used in the AEC industry worldwide. However, this study focuses on Bentley® Systems. Bentley® launched its first software in the 1980s, MicroStation™, and has since developed it into OpenBuildings™ Designer, a comprehensive BIM software. This platform serves as a hub for managing large and complex building design projects. It supports multiple file formats and integrates with Microsoft Office and Primavera for project planning and 4D simulations.

Additionally, Bentley® Systems offers specialized products for photogrammetry and Infrastructure management, such as ContextCapture™, OpenCities™ Maps, OpenCities™ Planner, and other products approximately 40 products cover various areas within the AEC industry, all interconnected within the same platform (Bentley Systems, 2017).

Level of development and information needs

In UIM, Level of Development (LOD) and Information Needs are interconnected frameworks that define the geometric precision and the richness of metadata associated with urban infrastructure models. Together, they ensure consistency, interoperability, and effective decision-making across multiple systems, such as buildings, utilities, and transportation networks, throughout the project lifecycle.

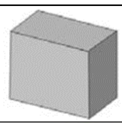
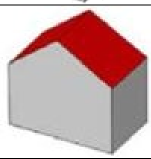
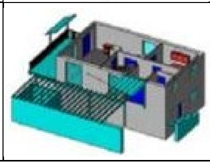
LOD and Information Needs are generally divided into five levels, each representing different stages of precision and information detail. At LOD 100, conceptual designs are characterized by broad, simplified shapes with approximate dimensions and basic functional metadata, supporting early-stage planning or zoning. LOD 200 represents schematic designs with approximate geometry and metadata, such as material types or basic operational details, suitable for feasibility studies. As the project progresses to LOD 300-350, detailed designs are developed with fully dimensioned models and operational data, such as load capacity and energy efficiency, making them suitable for construction documentation. LOD 400 includes fabrication-ready models with precise geometry and metadata for manufacturing and installation, including fabrication schedules and installation instructions. Finally, LOD 500 captures the exact as-built state of the infrastructure, enriched with advanced metadata, such as maintenance schedules, warranties, and operational data, to support long-term asset management.

An additional level, LOD 350, introduced in the American Institute of Architects (AIA) Digital Practice Documents, offers more detailed geometric and metadata specifications than other standards. However, this level has not yet been widely adopted and is not officially included in key AIA documents, such as AIA E203 – 2013, AIA G201 – 2013, or AIA G202 – 2013 2013 (Tritiptawinthorn & Khosakijjalert, 2015).

By integrating LOD and Information Needs, UIM aligns geometric precision and metadata richness with the specific needs of each project phase. This integration enhances interoperability and ensures seamless data exchange, which is critical for managing complex urban environments. Furthermore, it provides a robust foundation for advancing smart cities and supporting infrastructure lifecycle management through Digital Twin platforms.

While the concept of LOD has been extensively developed for BIM, its adoption for UIM is still evolving, and specific guidelines are not yet clearly defined. Research on urban model development within GIS frameworks offers some insights (Gröger & Plümer, 2012). For example, CityGML is a widely recognized GIS standard that uses XML encoding to represent cities in 3D. It captures geometric shapes, and spatial relationships between elements, meanings, and appearances, offering five developments (see Table 1).

Table 1: LOD and information needs for 3D City modeling in the CityGML format

Level	Name	Graphic Data*	Description
0	Footprint		2D - 2.5D model with X, Y coordinates (and sometimes Z), suitable for regional-level applications.
1	Block		Basic 3D block model, typically a simple box shape, suitable for regional applications.
2	Coarse exterior		Includes shapes of roofs, building walls, and other structures like balconies. Differentiates ground, vegetation, and water surfaces. Suitable for city-level applications.
3	Fine exterior		Detailed exterior architectural features like doors, windows, and balconies, including roads, land use, buildings, bridges, and tunnels. Mostly used for city landmarks.
4	Interior		Includes interior structural and architectural elements, such as internal walls, furniture, and rooms. Primarily used for important landmarks.

*Source: Adapted from Gröger and Plümer (2012) for Non-Graphic Data

For non-graphic data, is not extensively mentioned in the documentation; however, it is displayed in the attribute fields.

Interoperability data exchange standards

File extensions and exchange formats for BIM are crucial for the AEC industry, ensuring efficient collaboration and data exchange. These formats can be categorized based on their specific purposes (Batty, 2013): (1) Raster Formats: Formats like .JPG, .GIF, .TIF, and .PNG are pixel-based and often used for images, maps, or satellite imagery, which are integrated into BIM projects for visualization and background layers; (2) 2D Vector Formats: Formats such as .DXF, .DWG, and .SVG are used for precise technical drawings in urban planning and design. These formats allow for accurate representation of geometry in 2D, such as for roads or utilities; (3) Shapefile Formats: These formats, such as .SHP, are essential in GIS and are used to represent spatial data, including zoning layouts and boundaries; (4) 3D Surface and Shape Formats: Formats like .STL, .OBJ, and .3DS provide 3D models of surfaces and objects, used primarily in rendering and modeling urban environments. They are widely employed for presenting the structural and aesthetic aspects of urban elements; and (5) 3D Object Exchange Formats: These are the most crucial for BIM processes. Formats such as IFC (Industry Foundation Classes) and CityGML enable the exchange of 3D objects and metadata between platforms. IFC, managed by buildingSMART, is an open standard facilitating interoperability in BIM workflows, especially for infrastructure projects. It includes Levels of Detail (LOD) and Information Needs, integrating both graphical and non-graphical data across a building's lifecycle. CityGML, on the other hand, is widely adopted for urban-scale modeling, supporting both geometric and semantic information for urban objects, such like buildings and infrastructure.

By adhering to international standards like ISO 10303 (STEP), these formats ensure smooth compatibility and seamless data exchange, which is critical for collaborative AEC projects and efficient urban management systems.

Urban model and research gap

Urban models are crucial for visualizing, analyzing, and managing cities. Traditional models, often GIS-based, excel in spatial representation and data storage but lack real-time processing and dynamic analytics essential for managing modern urban infrastructure. These limitations hinder their effectiveness in addressing the demands of smart cities, where continuous data updates and integrated analytics are critical (Kolbe, 2009).

CityXML, an XML-based schema, facilitates interoperability in representing 3D urban models. While effective for data storage and exchange, CityXML is limited by its static nature and inability to handle real-time updates or dynamic data manipulation. Moreover, its XML structure can struggle with scalability for large, complex datasets, constraining its application in high-performance analytics and adaptable smart city systems (Biljecki et al., 2016).

BIM surpasses traditional models and CityXML by integrating dynamic, information-rich models across a building's lifecycle, from design to maintenance. It supports real-time data updates and interoperability through standards like IFC. However, BIM's primary focus has been on individual buildings rather than entire cities. Although it shows potential for urban planning, BIM's limited capacity for handling citywide datasets has led to the development of UIM (Sacks et al., 2018).

UIM extends BIM principles to city-scale applications, integrating data across various domains, including roads, utilities, transportation, and environmental systems. By enabling real-time data exchange and monitoring through Digital Twin concepts, UIM supports predictive analytics and informed decision-making. Unlike CityXML, UIM offers a dynamic, integrative approach, making it invaluable for sustainable city planning and smart city initiatives. However, UIM remains an emerging field, with ongoing research addressing its scalability, interoperability, and alignment with standards like CityGML (Batty, 2013; Elsheikh et al., 2021; Gil et al., 2011).

Despite its utility in representing static urban data, CityXML exhibits significant limitations compared to BIM and UIM: (1) Data Integration and Interoperability: While CityXML facilitates 3D data exchange, it lacks real-time updates and dynamic system integration, critical for smart city initiatives. In contrast, BIM and UIM support standardized frameworks like IFC and continuous data updates, enabling seamless platform integration; (2) Real-Time Data and Digital Twin Capabilities: CityXML does not support real-time data feedback or Digital Twin creation. UIM addresses these gaps, enabling real-time monitoring and predictive analysis essential for traffic management, environmental monitoring, and resource distribution; (3) Scalability and Data Complexity: CityXML's XML-based syntax struggles with large, complex datasets. UIM offers scalable solutions with parametric modeling and attribute-rich data integration for managing diverse urban sectors; (4) Sustainability and Predictive Analytics: CityXML lacks tools for sustainability assessments and predictive modeling. UIM and BIM provide advanced analytics for energy use, emissions, and resource management, aligning with sustainable development goals; and (5) User Adaptability and Interface Support: CityXML's data-centric structure is less user-friendly than the adaptable interfaces of BIM and UIM, which cater to various urban stakeholders, improving accessibility and collaboration.

In summary, while CityXML is effective for static data representation, it falls short in addressing modern urban management needs. BIM and UIM, with their capabilities in real-time integration, Digital Twin development, and sustainability modeling, are better suited to the dynamic and scalable requirements of smart city development.

CONCEPTUAL FRAMEWORK OF RESEARCH

A conceptual framework for UIM aimed at being an efficient management tools for cities requires covering various key components related to physical space and construction associated with engineering and urban construction in general. Therefore, the important components of the UIM may include the following (Figure 1):

1. **Building module:** This includes residential and commercial buildings such as houses, shops, offices, temples, historical sites, or other structures intended for habitation or use, as well as various parts of buildings, fences, walls, and signs.
2. **Transportation infrastructure module:** This encompasses infrastructure related to transportation, such as roads, bridges, railway systems, ports, etc.
3. **Utility infrastructure module:** This covers infrastructure related to public utilities and services, such as electricity, water supply, wastewater treatment systems, etc.
4. **Energy infrastructure module**: This includes infrastructure related to energy production and distribution, such as dams or power plants, etc.
5. **Urban furniture module:** This encompasses furniture or equipment within urban areas, such as trash bins, public benches, signage, etc.
6. **Recreational facility infrastructure module:** This covers areas designated for sports and recreational activities, such as sports fields or public parks, etc.
7. **Tree and shrub module:** This includes information about trees and shrubs within the urban area.
8. **Water & environmental and supply management infrastructure module:** This covers infrastructure related to water management and environmental facilities, such as wastewater treatment systems and water storage facilities, etc.

Developing a UIM that encompasses these components will help city managers plan and manage cities more efficiently, creating more sustainable and efficient urban systems.

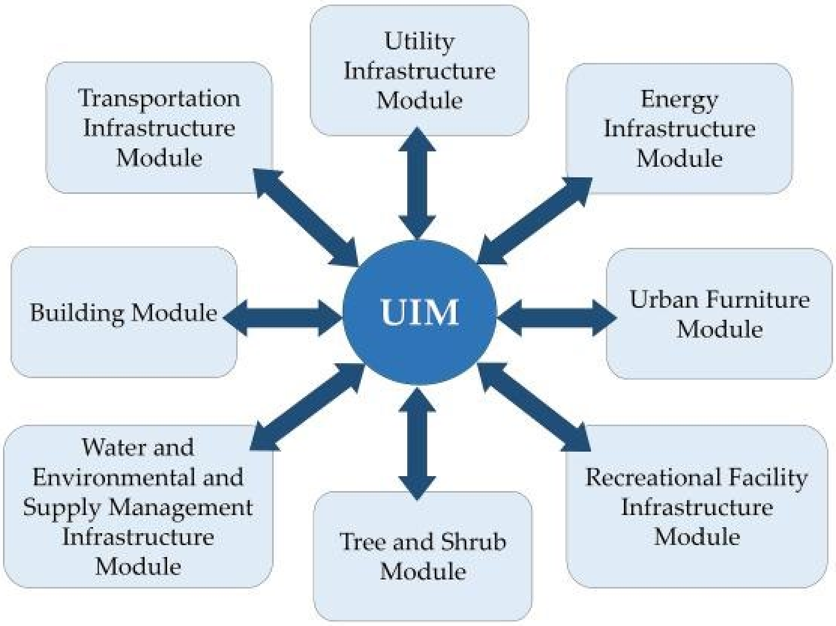


Figure 1: Module of UIM

Therefore, the development of UIM requires a diverse approach to encompass various components, particularly data interoperability, to ensure the highest efficiency of the developed models. As a result of expanding the concept of BIM to play a significant role in architecture, engineering, and construction, it leads to the development of UIM, consisting of the words "Information" and "Modeling." Thus, this research proposes a methodology for developing UIM, including both data and model components, by experimenting with the development and integration of various types of models, such as BIM Models, Block Models, Point Cloud Models, Reality Models, 3D Geographic Models, Raster Data, IFC, Shapefile, and 2D CAD, based on the expanded concept of BIM. Additionally, it outlines data workflows on the model for civil engineering and construction tasks (Figure 2) to ultimately achieve sustainable urban management.

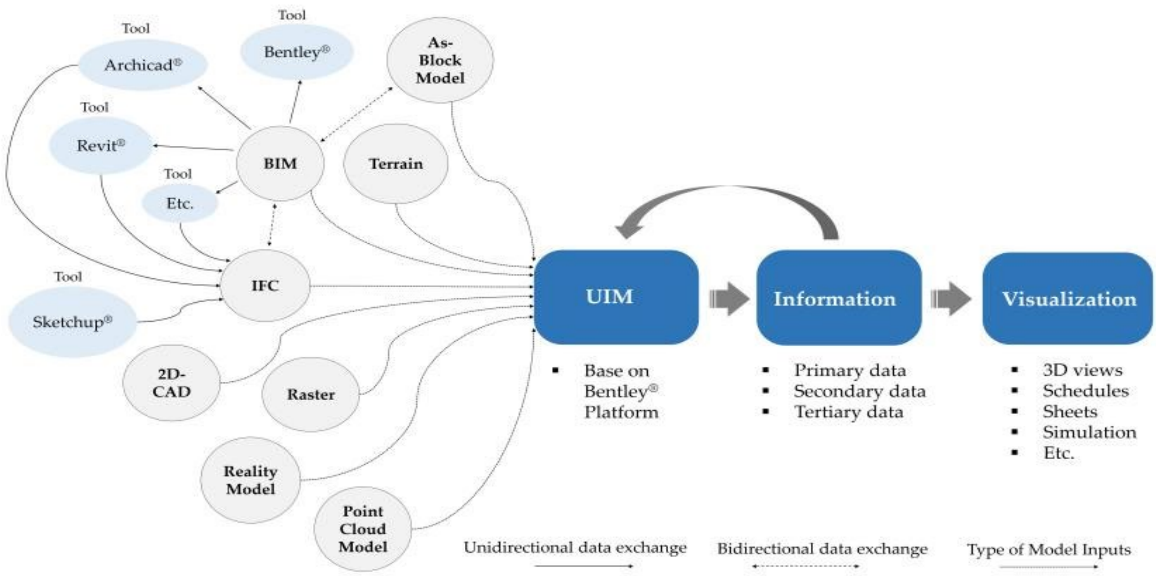


Figure 2: Conceptual framework of UIM

Normally, local administration officers (Thailand), acting as city or area owners, often receive UIM from construction projects they oversee, particularly for new construction. This is because, in current practices, construction contracts between owners and contractors (both private projects and public projects) commonly specify requirements for delivering BIM or various infrastructure models upon project completion or closure. However, for projects executed by other agencies, obtaining information models often occurs through the construction permitting process. Those intending to construct, modify, demolish, or remove buildings must submit documents, site plans, blueprints, component lists, and calculations.

Furthermore, local administration officers, in their capacity as custodians of the city or area, have the authority and responsibility to grant or deny construction permits. If there is a city information model, it facilitates the examination of land ownership, laws, and regulations, urban planning zones, or the assessment of impacts on surrounding communities or the general public before taking any action (approval or disapproval) more conveniently. This includes coordinating work (the ability to visualize both graphic and non-graphic information) with other government agencies. For the public sector, using UIM helps in defining building design concepts, and construction planning, which can examine legal matters, city planning, and simulated environmental impact assessment scenarios in surrounding communities more conveniently (Figure 3).

The development of UIM for existing constructions can utilize block models and BIM obtained from previously permitted and stored plans, alongside the development of realistic models derived from various surveying techniques to match current realities and serve as reference data. This can be done in conjunction with other model types like 2D CAD, IFC, shapefile, digital terrain model, and blueprint or scanned map file data for visualization (graphic and non-graphic) and application in civil engineering and construction throughout the construction lifecycle. This covers pre-construction stages (e.g., architectural drafts, design, cost estimation, bidding documents, contracts), construction stages (contractor-owner agreements, material and expense lists, progress reports, as-built drawings), and post-construction stages (maintenance, demolition) to propose workflow procedures. The aim is for this UIM development methodology to apply to various settings such as schools, universities, housing projects, residential areas, local administration organizations, communities, villages, or area development projects.

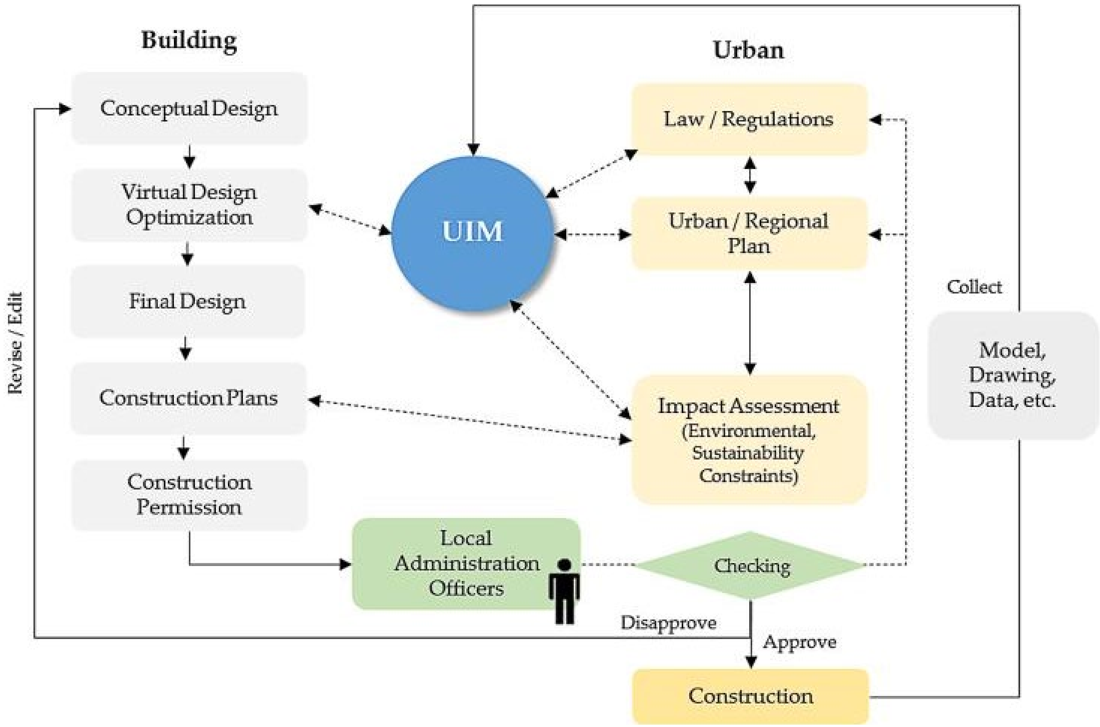


Figure 3: Typical process flowchart of the work of local administrative officials at the building level and city level and how the UIM framework will fit into the current model

RESEARCH APPROACH

The proposed framework follows a structured, five-stage process encompassing data collection, UIM development, proof of concept (case study application), discussion, and conclusion (see Figure 4). The following sections provide more details on each of these steps.

Data collection

This section incorporates data from prior studies, the master plan of the case study (Naresuan University), maps, satellite imagery, topographic data, blueprints, site surveys, and utility information such as water usage, traffic, and electricity consumption. Data collection involves interviews with experts and stakeholders in urban management, including personnel from NUDBA and relevant public agencies like local administrative offices, the Department of Public Works, and the Provincial Electricity Authority. Target groups include urban planners, engineers, architects, managers, and policymakers. Interview topics focus on model requirements (graphical and non-graphical data), operational needs, workflows, and infrastructure requirements.

Development of the UIM

This step describes the development process of UIM, both graphically and non-graphically, using Bentley's platform under the copyright of Naresuan University. The tools used include (1) OpenBuildings™ Designer: Used for creating, assembling, or modifying BIM, particularly for new buildings and files developed from other platforms; (2) ContextCapture™: Utilized for creating and processing to obtain realistic models and 3D point cloud models; and (3) OpenCities™ Maps Ultimate: Employed for presenting and displaying the development of city information models.

The case study adopts Naresuan University in Phitsanulok, Thailand (Figure 5), assuming "the university is equivalent to a city." The total number of students, faculty, and staff exceeds 20,000 people, with the university offering programs across 21 faculties, including the Health Sciences Cluster with 8 faculties, the Science and Technology Cluster with 7 faculties, and the Social Sciences Cluster with 6 faculties. The university covers approximately 201 hectares and includes green spaces, public parks, reservoirs, buildings, infrastructure, public utilities, and above-ground and underground infrastructure. Additionally, there are various facilities and services, such as public transportation, sports fields, swimming pools, shops, demonstration school, and more.

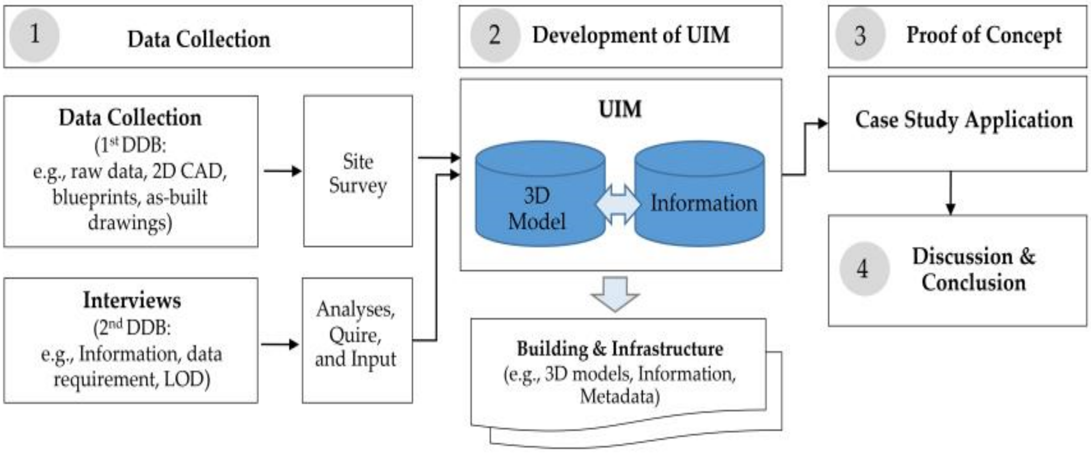


Figure 4: Overview of the proposed framework

The research divides the development into two main groups: (1) Building works; (2) Infrastructure works, both components comprise graphical and non-graphical data. Additional details will be discussed in the following section.

Case study application

This step involves applying the developed UIM in a real-world scenario for city management, following the framework of the NUDBA at Naresuan University, which is the agency directly responsible for managing buildings and infrastructure across the entire campus. The trial included facility management, such as new construction or planning for maintenance, including buildings, water systems, sewage systems, wastewater treatment, traffic signs, traffic lights, and other facilities. Additionally, it involved scenario simulations to assess building construction in compliance with national and local laws, such as checking setback distances, OSR (Open Space Ratio), FAR (Floor Area Ratio), impact assessments, and suitability, as well as ensuring proper connection to public utility systems linked to the buildings.

The purpose was to gather feedback and identify strengths, weaknesses, areas for improvement, and further development needs in the model. This would enable it to become a useful tool in engineering, construction, and urban management, supporting sustainable development in the future. This is particularly focused on the operation of digital twins to ensure sustainability for cities and the environment moving forward. The results were then discussed and concluded.

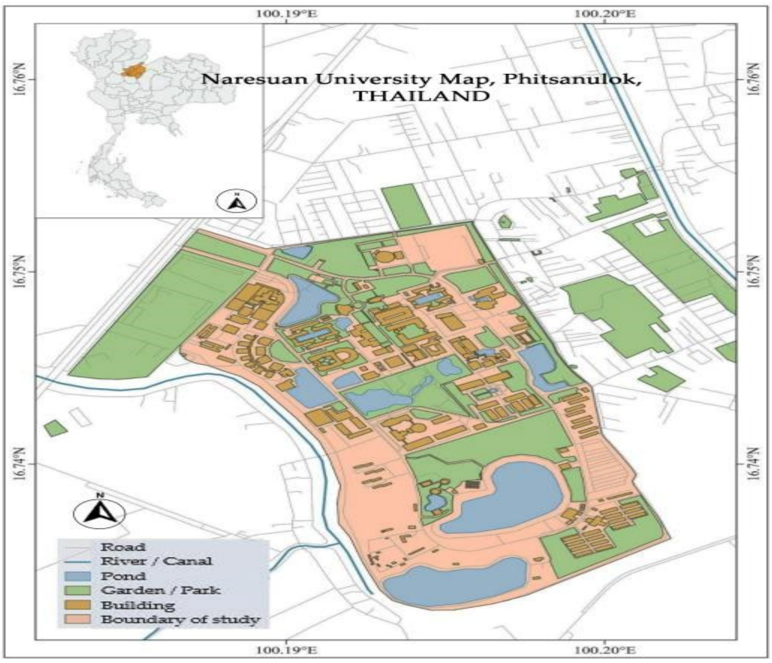


Figure 5: Naresuan university map, Thailand

DEVELOPMENT OF THE UIM

Step 1: Data requirements

The development of UIM is a complex process that requires careful consideration of user needs to ensure its effective use in sustainable urban planning and development. A critical part of this process involves interviewing 42 experts involved in urban management, to gain a comprehensive understanding of these needs. The interviews revealed that UIM development involves various approaches depending on the model's intended use. For internal organizational purposes, such as As-Built Drawings or models with a LOD 350 or higher, comprehensive graphical data is crucial. These models must accurately represent the shape, size, dimensions, and coordinates of buildings, along with thorough non-graphic data, covering the entire lifecycle from design to post-project. These models serve as databases for infrastructure planning and expansion, facilitating document retrieval for regulatory inspections.

For models used by external agencies or for inter-agency integration, a block model with a LOD between 200 and 300 is sufficient. This helps conserve resources and reduces confusion from overly detailed graphic data. Despite the simpler graphic format, block models still require organized non-graphic data, such as names, coordinates, dimensions, ownership information, and land boundaries, structured in layers using systematic methods like building codes or color divisions. The hierarchy of non-graphic data, based on the opinions from expert interviews, is summarized in Table 2.

Table 2: Non-graphic data layers required in UIM prototypes (arranged in descending order of importance)

Level	Internal Usage Data	External Agency Usage Data
1	Identifier / Name	Identifier / Name
2	Location, Coordinates, Building Type, Floor Count, Room Count, Exterior Dimensions	Location, Coordinates, Building Type, Floor Count, Room Count, Exterior Dimensions
3	Organization Category, Building Operation, Owner, Managing Agency	Organization Category, Building Operation, Owner, Managing Agency
4	Construction Date, Permit Applicant Name, Related Permit Information	N/A
5	Architectural Plans, Legal Documents, or Building-Specific Records	N/A
6	Operational Status, Maintenance Log, Demolition, Installations, Energy Consumption, Building Performance	N/A
7	Supplemental Data (Based on Organizational Objectives)	N/A

Step 2: The Development of graphical data in UIM

Building

The development of building models is categorized into three main types. First, BIM models are used for new buildings or those with detailed plans, with a Level of Development (LOD) of 350 or higher. These models include architectural, structural, mechanical, and electrical systems, as well as building amenities like fire extinguishers and emergency signs. Data is collected from blueprints and site surveys, ensuring accuracy and integration. Second, Block Models are used for older buildings with limited data, focusing on exterior features such as shape, height, and room count, with LOD between 100 and 300. Data is gathered through satellite imagery, drones, and ground-based surveys. Lastly, Reality Models are used for buildings with no prior data, created through unmanned aerial vehicle (UAV) aerial surveys and real-time kinematics (RTK) positioning systems for accurate mapping. While Reality Models cannot be converted directly into BIM (Batty, 2013), they serve as foundational references for future Block Models.

Infrastructure

The development of UIM infrastructure encompasses a wide array of urban elements, modeled at the Object level with a Level of Development (LOD) of 350 and above. Pipes and underground systems, such as water supply, wastewater drainage, electrical conduits, and underground cables, are modeled using BIM. Data is sourced from blueprint plans and field surveys to ensure the accurate geographic positioning of each component. Roads and walkways are developed using UAV surveys that employ a single-grid flight pattern at 30 meters altitude, capturing imagery with 80% overlap for precision. This data is integrated with BIM and IFC models to ensure comprehensive representation. The process includes various elements such as stone curbs, drainage channels, lighting poles, traffic signs, and electric poles. Ground control points and real-time kinetic surveys using stations from Thailand's Land Department enhance accuracy.

For urban objects, such as benches, fire hydrants, bus shelters, streetlights, and signal lights, BIM is used to create detailed models based on standard road and traffic infrastructure drawings following Thailand's Standard Drawing guidelines. Once modeled, these objects are exported into IFC format, with standardized objects stored in a library for future applications. Family & Part attributes are modified to match project-specific conditions, ensuring flexibility and adaptability for different urban contexts.

Water sources and irrigation features, including canals, reservoirs, ponds, and sluices, are developed into BIM using LOD 350 or above, ensuring high detail and accuracy. Data for these features is gathered from blueprints, construction documents, aerial photography, and on-site surveys, which help in mapping their precise locations. Landscapes and base maps are created using raster formats like JPG, GIF, and TIF, combined with GIS data from sources like university master plans. Actual field surveys are conducted to capture landscape features and ensure that the models are as accurate as possible. Trees and shrubs are modeled using Reality Models derived from UAV surveys, similar to the methods used for roads and buildings. These are integrated into IFC development, either through in-house modeling or by using external models from commercial sources, and Family & Part attributes are adjusted to fit the specific conditions of the project.

Based on the details mentioned above, regarding the development of graphic data, it can be summarized as illustrated in Figure 6.

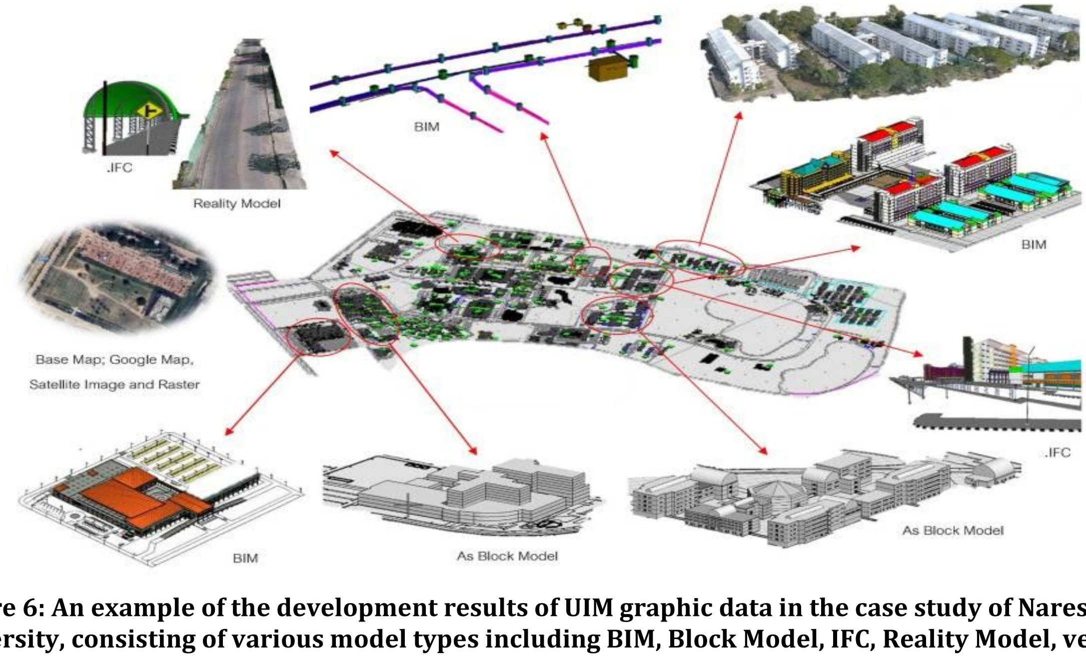


Figure 6: An example of the development results of UIM graphic data in the case study of Naresuan University, consisting of various model types including BIM, Block Model, IFC, Reality Model, vector (2D CAD, Shapefile), and raster

Step 3: The Development of non-graphical data in UIM

The development of non-graphical data in UIM is categorized into two types based on model characteristics: (1) Intelligent Models and Non-Intelligent Models. Intelligent models, including BIM, Block Models, and IFC standard formats, use software commands to create highly detailed objects with essential data like object code, color, level, geometric values, Family & Part, and material properties. These models are stored in a predefined template, such as the Building Template_USM in OpenBuildings™ Designer, and can be modified, including adding an "Urban" category for items like traffic signs and streetlights. Secondary data for these models include 2D CAD drawings, contract documents, and other technical details, which are linked to the primary data through the "Link & Attach File" command.

(2) In contrast, Non-Intelligent Models, such as Reality Models and Point Cloud Models, are not developed at the object level and have limitations, as they cannot be automatically transformed into a BIM. These models provide primary spatial data, such as dimensions and coordinates. Similar to intelligent models, non-intelligent models also include secondary data like CAD drawings, PDFs, and specifications, which are linked to external databases through the "Link & Attach File" command, just like with intelligent models or BIM.

All non-graphical data will be embedded within the model components and will be displayed when accessed by the user through software commands. The development results are summarized in Figure 7.

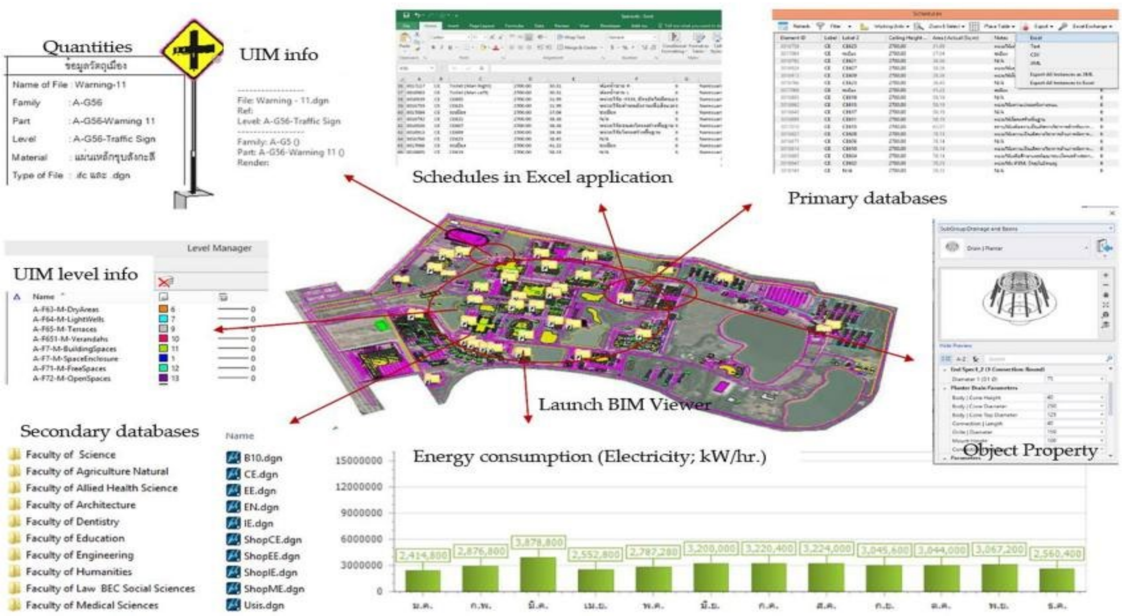


Figure 7: An example of the development of UIM graphic data in the case study of Naresuan University, which is embedded within model components and will be displayed when accessed by the user through software commands. Such information includes object properties, schedules, UIM info, quantities, or other data specified in the UIM

Step 4: Integration of all data on the platform

The model integration process for UIM leverages two main software platforms: OpenBuilding™ Designer for the primary model integration and OpenCities™ Map for visualization and user interaction. These platforms work seamlessly together to enable an effective and streamlined integration process. The first step involves importing base maps, which include university campus layouts (in 2D CAD format), satellite imagery, and mapping services like Bing Maps or Google Maps. Additionally, Shapefiles from GIS data are imported to ensure accuracy in geographic positioning. All these base maps are set using the global coordinate system EPSG: 32647 WGS84/UTM Zone 47N to maintain geographic precision. Once the base maps are in place, models are inputted onto the platform using the "Reference" command, with all models stored in the same directory to ensure smooth integration and access.

Each model is then referenced individually on a per-file basis. The models are aligned point-to-point with the base maps to ensure they are positioned correctly. In cases where misalignments occur, adjustments are made using the "Move" function, with the base maps serving as a reference for accurate positioning. The coordinates for new models are set during this step. To improve navigation and usability, levels are named based on the type of model-whether it's a building, road, or another element like pole numbers. This organized system ensures that models are integrated seamlessly and accurately verified.

For non-intelligent models, such as reality models and point cloud models that cannot be directly converted into BIM, external database linking is used. These models serve as primary data sources and are linked through external databases using the "Link & Attach File" command in OpenCities™ Map. All non-graphical data must be stored in electronic formats within a structured folder system, with each building kept in a separate file. Sub-folders are used to enhance internal data organization, ensuring that all linked information is easy to access and manage.

By integrating both graphical and non-graphical data, the process results in a comprehensive UIM system. Examples of the integration process and results are provided in Figures 6 and 7, and the overall UIM development is summarized and illustrated in Figure 8. This integration process not only facilitates the smooth functioning of the UIM but also supports its use in urban planning, infrastructure management, and facility oversight.

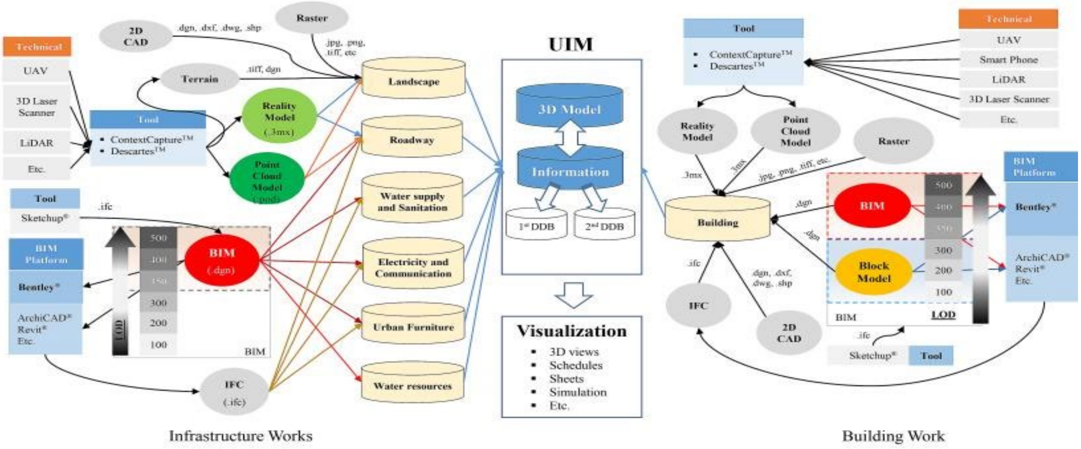


Figure 8: UIM system

CASE STUDY APPLICATION

Building approval process

The UIM system was tested with a case study building, a large reinforced concrete structure (6,800 square meters), which is currently undergoing the actual building approval process. The 3D file provided by the building owner (applicant) was submitted to NUDBA for verification to ensure compliance with legal requirements and regulations.

NUDBA tested the developed UIM as a tool to assist with this process, replacing traditional methods (2D drawings and manual processes). The 3D building model submitted for approval was developed using a different platform (Google SketchUp), so it was imported into UIM in the .IFC format. Users then analyzed the data from UIM, checking it against legal regulations and government standards. This included verifying construction location, FAR (Floor Area Ratio), OSR (Open Space Ratio), and existing environmental factors such as light and shadow. It also checked connections to public utilities and infrastructure elements like water supply, drainage systems, street lighting, and road access to the building, as well as construction methods to mitigate long-term impacts (Figure 9).

This test aimed to determine whether using UIM, which integrates both graphical and non-graphical data into a comprehensive urban and engineering database, would enhance the speed, accuracy, and efficiency of inspections and decision-making processes for the staff involved.

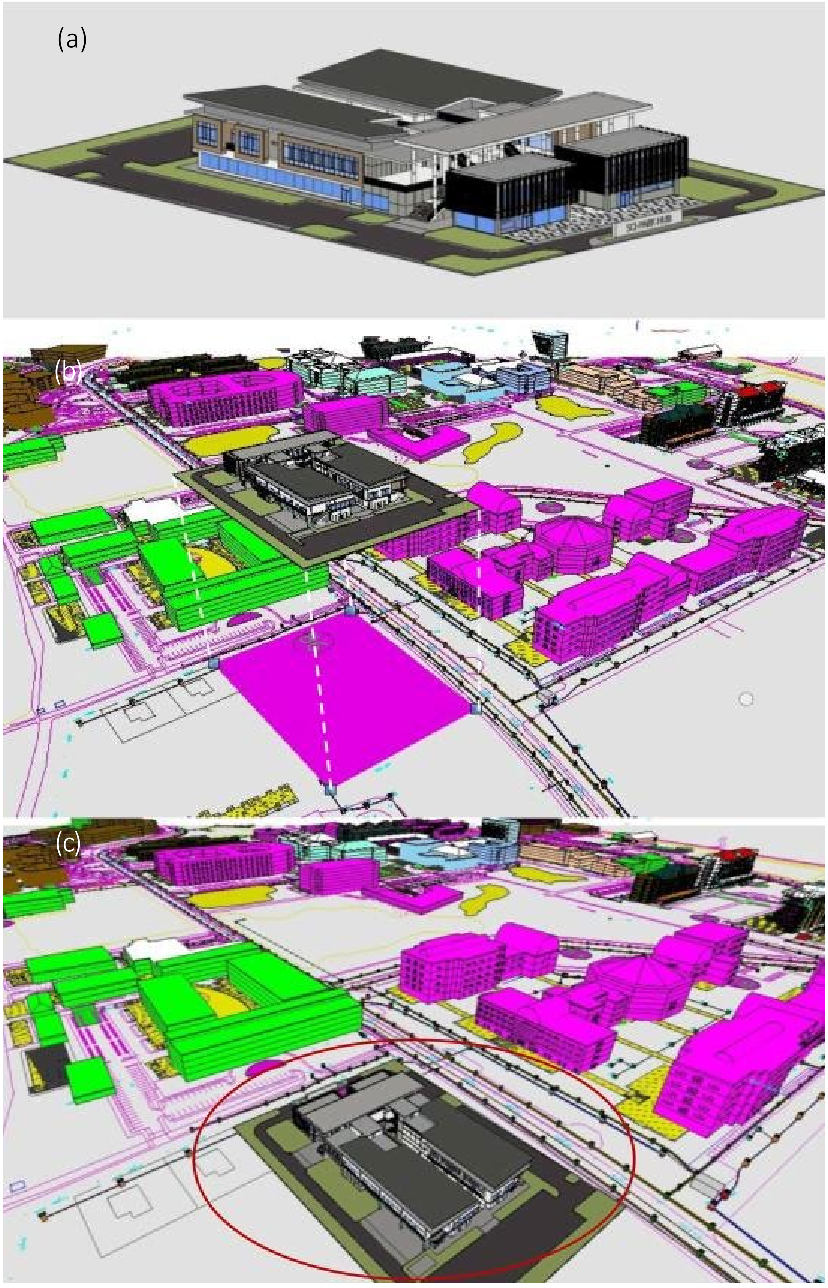


Figure 9: Demonstrate the application of UIM by importing the model of a proposed building: (a) in IFC format into the UIM database; (b) to verify whether the setbacks (OSR, OFR); and (c) utility systems comply with applicable standards, regulations, and building control laws

Monitoring construction, maintenance, and management

This trial was conducted on an underground drainage construction project located within the case study area. This project had a unique characteristic it involved new construction that needed to connect to an existing system while also laying the groundwork for future extensions in the coming years. The drainage construction was challenging due to the underground structures being at varying depths (with sloped pipes) and mostly situated beneath other infrastructure, such as roads, sidewalks, and lawns.

Furthermore, there were various types of pipes buried underground, including electrical cables, water supply pipes, and sewage pipes. Without accurate and sufficient data, unplanned excavation or dismantling of other infrastructure could result in both direct and indirect damage, excessive budget consumption, and disruptions to the daily lives of city residents.

In this process, the developed UIM was used as a tool to help identify the precise locations and material properties of pipes and nearby structures, as well as other facilities. This included details such as pipe types, materials used, maintenance history, concrete road thickness, the size of building foundations near excavation sites, and available space for material storage during construction. Additionally, construction and maintenance records were incorporated into the UIM database to promote sustainable urban management, replacing the traditional manual approach.

This trial aimed to test the capability and accuracy of UIM, particularly its non-graphic data, in supporting the sustainable management of urban infrastructure, utilities, and services issues that are prevalent in nearly every city.

Figure 10: Integration of UIM in underground drainage pipe construction: (a) pipeline layout map showing connections and pipe positions; (b) intelligent model simulation of the drainage system with graphical and non-graphical data for planning and assessment; (c-e) stages of excavation and pipe installation.

Based on the UIM trial mentioned above, when assessing the performance of UIM by surveying target users-including managers, civil engineers, electrical engineers, architects, draftsmen, general administrative officers, and landscape architects. It was found that 14 out of 15 users provided feedback on their satisfaction levels after using the UIM process to assist with work and urban management, compared to traditional methods that relied heavily on documents, 2D plans, and manual work.

In this evaluation, satisfaction and opinions were gathered on three main aspects: 1) Efficiency of usage and data integration; 2) Investment value and return on investment; and 3) Improvement of public services and responsiveness to public needs. The feedback on satisfaction and opinions is summarized in Table 3.

Table 3: Summarizes the user feedback on satisfaction and opinions

Item	**Level of Satisfaction* (average)**
1. Effectiveness of data usage and information management	
• UIM can manage various data types, such as data from UIM, for easy access, reducing data redundancy, and supporting multiple perspectives.	Very Good

• UIM can display 3D data clearly, assisting in understanding spatial information (graphics or via devices like drones) from various tools.	Very Good
• UIM can efficiently retrieve data from various platforms, such as GIS, Google Maps, Google SketchUp, and Microsoft Excel.	Very Good
• The accuracy of the data obtained from UIM impacts decision-making in policy and operations.	Very Good
• UIM is a tool that helps manage urban data with greater clarity and ease of use, leading to more sustainable urban management.	Very Good
2. Investment convenience and return on investment	
• UIM can help reduce the costs of urban system management in the long term.	Strongly Agree
• Using UIM improves decision-making regarding the management of physical resources and enhances investment efficiency.	Strongly Agree
• UIM reduces time or errors in investment and urban development projects.	Strongly Agree
3. Adjustability of service systems and public engagement	
• UIM helps improve public services like infrastructure systems, transportation, and energy management.	Agree
• Do you believe that UIM is flexible enough to add new features to support public participation in decision-making processes?	Neutral
• UIM can manage and retrieve data efficiently in response to sudden or unexpected changes in urban environments	Agree

*Satisfaction levels were categorized into 5 levels: Level 1 (Strongly disagree / Very poor); Level 2 (Disagree / Poor); Level 3 (Neutral / Fair); Level 4 (Agree / Good); and Level 5 (Strongly agree / Very good).

DISCUSSION

Based on the research findings, the development of the UIM methodology for managing physical resources within civil engineering works extends the concept from BIM to include both graphical and non-graphical data. This approach integrates models of both new and existing structures to create an intelligent model. Naresuan University was used as a case study under the assumption of "The University as a City." The proposed UIM methodology was found to be capable of developing UIM to support civil engineering and physical resource management in line with the research objectives as follows:

1. Development of information models

The development of UIM includes both building and infrastructure works according to the proposed UIM methodology, consisting of various types of models, summarized technically as follows:

BIM

This is considered an intelligent model suitable for constructions with sufficient data to be developed into a BIM, such as buildings, bridges, tunnels, water systems, wastewater treatment systems, or others. The development level starts from LOD 350 up to As Built Drawing (LOD 500). The model development must follow BIM principles systematically, using compatible platforms, versions, templates, and software databases (in the case of multiple computers). If premade object tools from software databases are not used, form type parts should be employed to develop objects since these are more intelligent than solid types, which cannot define surfaces or certain information within the objects.

The data beyond the primary (non-graphical) information attached to the model parts from the software database must include necessary details such as ID code, level, family & part, area, room information, or other relevant details. Secondary data are linked to external databases, applicable to all data types, including electronic files (.pdf), spreadsheets (.xlsx), Microsoft Access, .docx, 2D CAD

(.dgn, .dxf, .dwg), .jpg, .png, .tiff, or others. The linked data must be categorized into organized folders and subfolders for ease of use.

Block model

This intelligent model is suitable for construction with insufficient data for a BIM and is suitable for models that do not require high details. The development level is below LOD 350. This model focuses on the size, dimensions, and external shapes of buildings, mainly used at the urban level (to save computing resources compared to BIM).

The development should use compatible platforms, versions, templates, and software databases (in case of multiple computers and supporting conversion to BIM). Form-type parts should be used for development (for the same reason as with the BIM).

Data beyond the primary (non-graphical) information attached to the model parts from the software database must include necessary details such as ID code, level, family & part, area, room information, or other relevant details. Secondary data are linked to external databases in the same organized manner as in BIM.

IFC

This is an intelligent model developed from BIM, focusing on size and dimensions and suitable for urban objects or public facilities such as traffic signals, street lighting, traffic lane dividers, utility poles, traffic signs, tactile paths for the visually impaired, trash bins, fire hydrants, trees, and shrubs. Once developed, these standardized objects can be used multiple times, and they are platform-neutral (cross-platform compatible). However, the process of cross-platform data exchange in the standard IFC format is still not fully refined (data loss, damage, or display errors often occur) and requires further development. For secondary data, external databases are linked similarly to the BIM and Block Models.

Reality model or point cloud model

These models are developed from aerial surveys using UAVs. They are suitable for buildings with insufficient data to develop other types of models, urban scale work, road projects, large-scale terrain works, etc. The development of this model requires proper flight planning and must always be accompanied by ground control points to ensure coordinate accuracy.

The use of this technique to develop reality models has caution points, such as surveying in restricted areas and challenges with indoor surveys compared to other technologies like 3D laser scanners and LiDAR. Lighting and shadows are also obstacles, as improper timing during UAV data collection may result in building or surrounding shadows blocking target objects, leading to processing errors.

Surveying roads or routes to assess damage or maintenance may require traffic closure during UAV flights since high angle image capture may obscure road conditions (similar to shadow problems). Captured images may include vehicles, leading to processing errors or incomplete results.

Other data

This includes raster, Terrain models, and 2D CAD, including base map data from service providers like Google Maps and Bing Maps. These are two-dimensional graphical data with non-graphical information in attribute tables, mainly used as base maps for developing UIM, commonly displaying land boundaries, deeds, topography, etc. Secondary data are linked to external databases similarly to other model types.

Data in information models

In cases where internal departments (acting as owners of buildings, cities, or city managers) are involved, models should be developed at the construction level to the As-Built Drawing level entirely. Graphical information should include structural, architectural, and system work, as well as water supply and sanitation systems, including land boundaries or deeds. Non-graphical information should include (1) ID or model name; (2) building details such as location, coordinates, building structure type, number of floors, number of rooms, external dimensions; (3) organization type, building business, owner, responsible unit; (4) construction date; (5) legal documents such as building permits; (6) usage status, maintenance history, demolition or installation details, energy usage information; and (7) other relevant data as per the mission.

When external departments are involved, requiring block model data from LOD 200 to 300 is sufficient. Higher-level graphical data would waste computing resources and lead to unnecessary complexity. Nevertheless, essential non-graphical information should accompany the model, including the name, dimensions, owner or responsible organization, and coordinates (especially land boundaries and deeds).

2. Integration and application of information models in case studies

For local administrations or building management departments acting as city owners, new UIM obtained from contractors (for projects constructed in-house) are usually stipulated in construction contracts between owners and contractors (for both private and government projects), specifying the delivery of BIM or various infrastructure models upon project completion or closure.

For old constructions, UIM can be developed from approved and stored construction plans, along with developing reality models obtained from various survey techniques (as reference data). The data is integrated with other model types such as 2D CAD, IFC, terrain models, and scanned map files to display both graphical and non-graphical data, supporting civil engineering and construction works.

From the application of UIM in processes such as construction permit approval, construction supervision, maintenance, and urban facility management in the case study, it was found that UIM, in the aspect of Efficiency in usage and data integration, improved efficiency in accessing and managing data compared to traditional methods according to most users. In the aspect of Investment value and return on investment, UIM helped reduce costs and improve decision-making in resource management. In the aspect of Improvement of public services and responsiveness to public needs, users agreed that UIM enhanced public services and enabled better responsiveness to urban changes.

Additionally, UIM can be applied across various urban sectors, including infrastructure development, environmental management, urban administration, disaster prevention, security, taxation, and economic development. It serves as a database for planning, managing energy usage, simulating traffic, and addressing environmental issues like waste collection and water management. UIM aids in urban planning, construction permits, and disaster response, by identifying essential utilities and emergency routes. Furthermore, it supports crime prevention, tax collection, tourism promotion, and heritage conservation. UIM integrates data across sectors for sustainability to enhance decision making and ensure long term resilience.

The proposed UIM methodology expands BIM principles to manage physical resources in civil engineering, integrating graphical and non-graphical data. Using Naresuan University as a case study under the concept of "The University as a City," the approach effectively supports civil engineering and resource management.

CONCLUSION

UIM represents a significant advancement from traditional BIM, evolving into a comprehensive platform for sustainable urban management. By integrating graphical and non-graphical data, UIM supports Smart City Digital Twin initiatives, enhancing urban facility planning and management. The proposed UIM framework, demonstrated through a case study at Naresuan University, effectively combines diverse data sources such as BIM, block models, IFC standards, reality models, and GIS data. This integration facilitates collaborative infrastructure management while enhancing efficiency and decision-making. However, UIM adoption faces challenges, including high costs, interoperability issues, and the need for standardized data exchange. Addressing these barriers requires investment in technology and the incorporation of IoT and AI to enhance functionality.

In summary, UIM offers a transformative approach to urban management, promoting efficiency, sustainability, and adaptability. Future research should focus on refining methodologies, improving interoperability, and exploring applications across various urban contexts to maximize its impact.

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