Journal of
Engineering Sciences
Faculty of Engineering
Assiut University
JES
مجلة
العلوم الهندسية
كلية الهندسة
جامعة أسيوط
journal homepage: http://jesaun.journals.ekb.eg

An Integrated BIM and GIS Framework for Sustainable Urban Planning

Received 4 February 2025; Revised 23 March 2025; Accepted 23 March 2025

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Keywords
Urban Planning, BIM, GIS, Infrastructure, Urban Areas, Pedestrian Network

Abstract: Urban planning has various issues as cities expand rapidly, population density rises, and urban infrastructure becomes more complicated. Poor exploitation of resources such as land, energy, and water has contributed to environmental degradation and unsustainable development. The lack of integrated data systems for the management of building and geographical information complicates decision-making in the process of urban planning. This may result in congestion, insufficient public services, energy inefficiency, and inadequate environmental management. Such issues require an integrated solution in urban planning, from specific building-level data to wide geographical information, in order to maximize resource utilization and improve the quality of life in urban areas. The paper proposes an integrated BIM and GIS framework to take up the challenges in urban planning within high-density environments. The integration of the thorough building models of BIM with the spatial context of GIS allows comprehensive urban analysis, hence enhancing decision-making for growth in sustainable cities. It also allows the running of advanced simulations such as energy use, flow of traffic, and environmental impact studies. Furthermore, it has aided in improving collaboration between planners, developers, and other stakeholders, in order to create more comprehensive urban development strategies.

1. Introduction

With the increase in population and emission of greenhouse gases, urban planning has become increasingly important. It is defined as the art of designing and setting up cities and towns to provide a sustainable, functional, and livable environment for its inhabitants [1]**.** As urban construction accelerates, modeling and simulation are seen as valuable tools for improving urban planning. The growing availability of 3D city models has made it possible to perform simulations at different scales. While Building Information Modeling (BIM) allows users to explore variable options for individual buildings, GIS-based models enable simulations of urban planning demand at the city-wide level [2]**.** BIM and GIS provide an unprecedented way to bring in the geo-data in multi-level stages while making the

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https://doi.org/10.21608/jesaun.2025.358173.1422

efficiency, reasonability, and intelligibility of city planning maximally efficient [3]**.** The rationale of integrating BIM and GIS does not solely lies in utilizing available 3D models in a perfect manner, but also in connecting it with others related fields that consist of city planning, architecture, and environmental engineering in such a way so as to offer interference-free connections. While 3D models are widely used for visualizing and presenting city features, they have not yet reached their full potential. Integrating BIM with GIS allows for the inclusion of detailed BIM data in large-scale spatial analyses, improving the precision of urban evaluations and thereby informing urban planning and decision-making [4]**.** Accordingly, this paper intends to present a comprehensive integrated framework for utilizing BIM and GIS in urban planning to address the issues of urban planning within high-density environments and improve decision-making for growth in sustainable cities.

2. Sustainable Urban Development

Cities account for 55% of worldwide population, and they contribute 85% of global gross domestic (GDP) product and 75% of greenhouse gas emissions. SDG-11, Sustainable Cities and Communities, seeks to ensure inclusive, resilient, and sustainable urban and human settlements by providing low-cost transportation solutions, reducing urban sprawl, increasing urban governance involvement, protecting cultural assets, and addressing urban resilience and climate change issues [5]. Sustainable urban development is a top priority for cities worldwide, driven by environmental, political, economic, and cultural challenges where urban planning and sustainability are closely intertwined. Rapid urbanization presents challenges that call for resilient planning and development perspectives, accordingly, sustainable urban development aims to address the impacts of rapid urbanization, offering new mechanisms for building an urban future.

With the rise in the urban population comes the demand for efficient land use, infrastructure, and public services that create many challenges that need to be considered and coordinated with great care. Urban planning faces several challenges, including population growth, housing affordability, transportation, infrastructure, and climate change. Rapid population growth leads to overcrowding, increased stress on resources, and increased property prices. Housing affordability outstrips supply, causing high property prices and forced migration. Congestion and lack of proper public transportation contribute to pollution, energy consumption, and decreased quality of life. Infrastructure needs to be scalable and resilient to future demand. Climate change also poses risks, necessitating strategies for resilience. Buildings requiring increased energy use require advanced energy policies and improved energy performance to achieve urban sustainability goals [6]. Technological integration, governance, and policy coordination are crucial for urban planning initiatives [2]. Overall, urban planning needs to balance the needs of current residents with future demands, ensuring that cities remain inclusive, functional, and sustainable in the face of rapid change and growing challenges. Nowadays, technology has developed solutions, working techniques, and strategies that enable faster and more accurate solutions. Geographic information systems (GIS) and Building Information Modelling (BIM) are powerful tools for urban design, linking data with physical form and connecting planning regulations with the city [7]. However, BIM methodology is not practical for creating large-scale urban areas, so the integration between GIS and BIM is essential for enhancing work and developing solutions.

3. Research Methodology

The research follows a qualitative methodology where it starts with a theoretical study that provides a thorough literature review on the role of GIS and BIM integration in enhancing the urban planning sustainability, followed by a review on the workflow of both GIS and BIM and the different integration levels. Then, the analytical study where the research examines and analyzes three case studies that have utilized these two technological tools to improve urban planning sustainability. It aims to identify the necessary data, steps, and procedures required to apply these tools at different city levels. The combination of the theoretical and analytical studies provides guidelines for the integrated use of BIM and GIS to enhance different planning aspects in urban areas. It presents a comprehensive framework for the key actions and requirements for conducting: Building Site Context with the Environment, Semantic Pedestrian Network, and Energy Performance Map, specifying the input and output data for both BIM and GIS. Implementing these proposed methods in both new and existing neighborhoods will significantly promote energy conservation, reduce harmful emissions, protect the environment, and support sustainable development.

4. Overview of BIM and GIS Integration

BIM is regarded as the most crucial development in recent times in the fields of architecture, engineering, and construction. It has been in practice in the construction industry for many years before becoming known to GIS professionals. BIM was developed to enhance the coordination and information flow among different stakeholders during a construction project. It includes the formation of digital models that represent the physical structure of a building and its precise geometry, hence allowing for better analysis and management. BIM has already been integrated into land administration systems through the concept of 3D cadaster in various cities around the world [8]. Accordingly, the Industrial Foundation Classes-IFC standard was developed as a reference to BIM models in the construction industry. The IFC was designed to capture all the details of a building project throughout its lifecycle. It is essentially a shared data model at its core. In addition to depicting the components of a building, IFC supports advanced processes and analysis by considering the spatial relationships between those components. The basic structure of an

IFC building model, as shown in Fig. 1, follows specifications from the International Alliance for Interoperability (IAI) and the International Standards Organization (ISO) in the official IFC standard documentation.

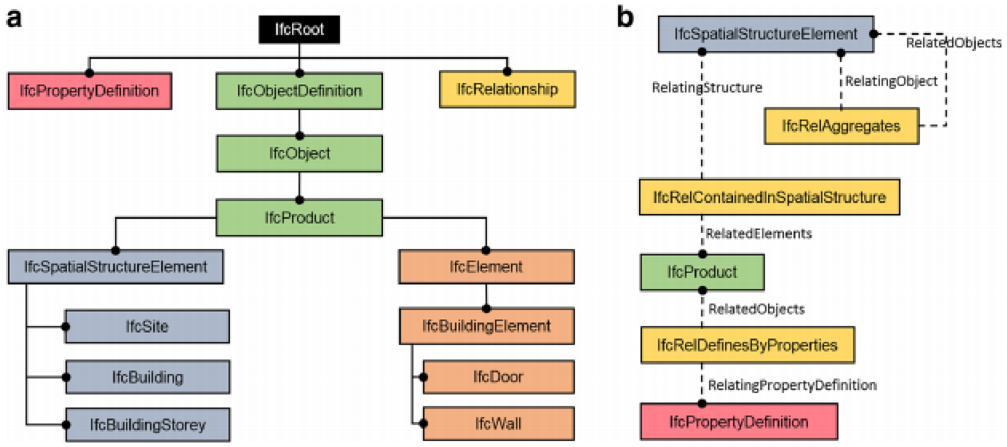

Fig. 1: Basic overview of the IFC hierarchy (a) and their relational assignment (b) using Express-G notation [4]

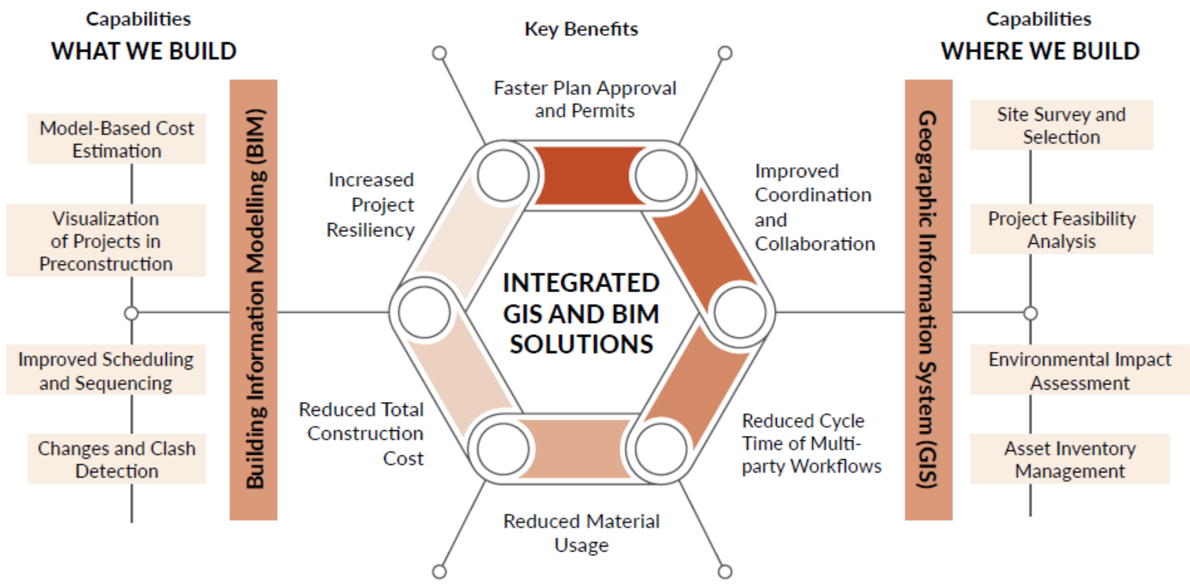

Fig. 2: GIS and BIM Integration [9]

Integrated GIS and BIM solutions provide digital means to make assessments on design compliance in support of non-intrusive techniques, as depicted in Fig. 2. Reduced construction cost and cycle time of multi-party workflows, increased project resiliency, improved coordination between different parties and reduced material usage, are all key benefits achieved by integrating GIS and BIM. GIS is involved by: site survey and selection, project feasibility analysis, environmental impact assessment and asset inventory management. In addition, making technical installations by way of spatial data and monitoring of energy consumption will produce a sustainable and energy-efficient infrastructure. From a geographic and geological perspective, GIS solutions simplify the understanding of how infrastructure projects impact the natural environment. BIM is involved by: model based cost estimation, visualization of projects in preconstruction, improved scheduling and sequencing, and changes detection, making project design reviews and structural load distribution and calculations more economical and effective. These integrated solutions also assist construction and contracting companies in assessing on-site health and safety, ultimately reducing risks in project execution. As a result, this combined approach supports environmental impact assessments for large-scale infrastructure and industrial projects, which are becoming mandatory in many countries [9].

5. BIM-GIS Integration Levels

In this regard, the proposed integration levels facilitate data interoperability to share information between BIM and GIS. Integration levels are divided into three main types, including data, process, and application levels. Data and process levels are divided into two sub-levels: geometric and semantic levels along methods based on semantic web technologies and services [10].

5.1. Data Level

Geometry Level: Differences in the reference system, 3D geometric representations, and Level of development (LOD) make BIM and GIS integrations at the geometric level a challenge. First, the reference systems are different: BIM has a local placement system while the GIS employs Geographic coordinate system (GCS). For transforming from one to another, a transformation matrix is necessary that comprises the bridging matrix M and origin difference. Alternatively, the transformation process involves three coordinate systems: the world coordinate system of T1, the local coordinate system of T2, and the local 2D coordinate system of T3. This allows for easy conversion between the systems for different purposes [11]. The second difference refers to how BIM and GIS represent 3D geometry. BIM is based on the IFC format, which is a standardized open data model that, for volumetric objects, supports three representation methods: Constructive Solid Geometry (CSG), Sweep Solid (SS), and Boundary Representation (B-rep). On the other hand, GIS generally uses formats such as CityGML and shapefiles; CityGML relies on Boundary Representation for 3D geometry. As such, several conversion methods are possible between IFC and CityGML/shapefiles [12].

Semantic Level: A new method, the Word Hash Method based on Letter Trigram (WHSMM) [13], has been recommended as a more effective solution for language-based semantic mapping, offering superior performance for better transformations compared to other methods. Additionally, the Exact Transform and Load (ETL) process is designed to semi-automatically convert data between BIM and GIS. During this ETL process, BIM and GIS data are converted into the Resource Description Framework (RDF), addressing issues of data interoperability and meeting community energy design requirements [14]. This method is particularly useful for large-scale projects like urban communities, where abstract, low-level information is needed. The ETL approach not only supports batch data conversion but also enhances reusability and scalability. It was also verified in a prototype using Facilities Management (FM) that cases using BIM-GIS integration requires the development of new standards due to the differing standards used by BIM (IFC) and GIS (CityGML). To address this, the OGC IndoorGML standard was created as an application solution to facilitate the exchange of indoor navigation information. By applying the SPARQL query language, the ontology integration between the indoor information in IFC and the GIS ontology in OGC IndoorGML can be achieved.

Moreover, the OGC LandInd supports land and civil engineering infrastructure. While it has been recognized as a potential bridge between BIM and GIS for specific use cases, there is limited information available regarding software support and practical applications for OGC InfraGML. The IFC EXPRESS model can also be used to create a unified language (UML) that links BIM and GIS through schema conversion. Tools like ShapeChange, an open-source software, can be used to convert IFC to UML and then to GML, enabling more effective 3D visualization and evaluation [15].

5.2. Process Level

Semantic Web Technologies: At the process level, integrating BIM and GIS does not alter the data format or structure. Instead, the reference ontology, as part of the Semantic Web or Web Service, is utilized to enhance the cross-domain architecture mapping and store and demonstrate the differences between objects [16]. Semantic Web technologies contribute to better data interchange and partially satisfy the data needs for community energy design. Nevertheless, there are still obstacles to overcome in order to properly utilize these technologies, such as the Resource Description Framework (RDF) and Web Ontology Language (OWL). The absence of a sufficient knowledge base and a standard ontology is one of the main problems [17].

5.3. Application Level

At this level, integration solutions often entail developing or updating existing BIM or GIS systems to serve as information exchange and integration facilitators. This strategy, however, is sometimes expensive and inflexible because it is built for individual projects [18]. Creating specialized BIM plug-ins to retrieve required data from GIS and store it in a central database is one example of such a technique. Additionally, collaborative research projects that span all sizes and stages of the built environment lifecycle employ a multidisciplinary approach. This strategy facilitates the neighborhood-level holistic design of energy-efficient buildings, allowing for more sustainable project growth.

6. Application of BIM and GIS in Urban Planning

In urban planning, the use of GIS and BIM provides strong tools for managing and evaluating spatial and building-level data. According to Zhao and Liao (2018), these technologies facilitate sustainable development, improve decision-making, and aid in planning process optimization [19]. Fig. 3 provides an overview of how BIM and GIS are used in urban planning.

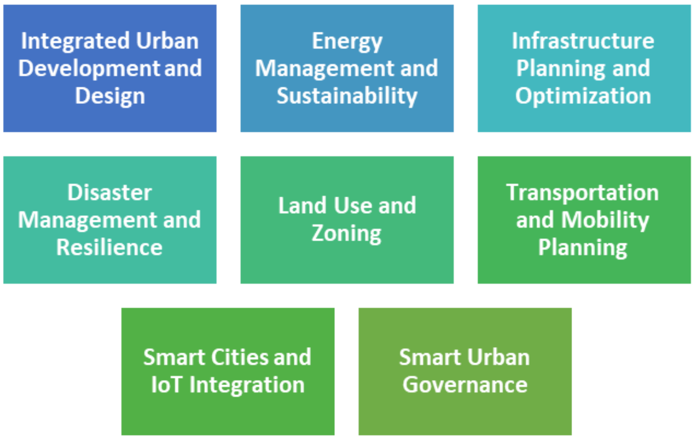

Fig. 3: Overview of BIM and GIS in Urban Planning

Integrated Urban Development and Design; In order to support the integrated design and development of metropolitan areas, BIM and GIS are increasingly being used in conjunction. While BIM is primarily used to model specific structures, GIS offers a more thorough spatial context. In response to the exponential growth of data sources, planners have employed these technologies to assess how new developments interact with the existing urban fabric, which encompasses the relationship between buildings and infrastructure and the surrounding environment [19].

Energy Management and Sustainability; Optimization of energy efficient urban design through the integration of BIM and GIS BIM assists in modelling the energy performance of individual buildings and provides insights into energy consumption or heating and cooling requirements, whereas GIS presents a holistic interpretation of environmental aspects such as solar radiation, wind flow, and heat islands at the urban or city scale [19]. These technologies work together to find opportunities for energy savings, renewable energy integration and heat island mitigation measures, resulting in more sustainable urban environments.

Infrastructure Planning and Optimization; Major infrastructure, including highways, utilities, water systems, and power grids, can be mapped and managed with the use of GIS, which excels at spatial analysis [12]. By giving specific details on how a building will interact with its infrastructure, BIM enhances GIS when applied to individual buildings. Combining the two allows planners to avoid interference with current systems, plan for future expansion, and strategically locate new infrastructure.

Disaster Management and Resilience; Combining BIM and GIS can improve urban resilience and disaster response. Though BIM offers a wealth of knowledge on building systems, materials, and systems, GIS offer the spatial context for mapping hazards including flood zones, earthquake-prone areas, and fire dangers [10]. This integration enables more exact risk assessments, emergency response plans, and the construction of robust infrastructure that can withstand natural disasters.

Land Use and Zoning; Land classification, zoning regulations, mapping property boundaries, and land use planning are all common uses of GIS in urban environments. Including BIM enables planners to assess how different building styles and types will fit with present land use ideas and zoning rules [11]. This ensures compliance with regulations and helps one to imagine future changes within the confines of already existing urban designs.

Transportation and Mobility Planning; Urban planning depends crucially on urban since of urban mobility. Essential information for transportation systems including road networks, traffic flow, public transit routes, and pedestrian paths are supplied by GIS works [19]. New developments and constructions' influence on transportation systems, including how new buildings will affect traffic patterns or how they fit with public transit, can be modelled using BIM. Together, this helps build more sustainable, accessible, and efficient transportation systems.

Smart Cities and IoT Integration; BIM and GIS are essential parts of the digital infrastructure in smart city contexts. Real-time monitoring and management of urban systems, such as traffic, utilities, and building performance, can be achieved through their integration with Internet of Things (IoT) technology [1]. The integration of spatial and building-level data from GIS and BIM with real-time data from IoT devices allows for more adaptable, efficient, and responsive urban management.

Smart Urban Governance; BIM and GIS facilitate governments in implementing more intelligent urban management by offering data-driven insights into the city's environment [18]. These ideas can help to shape policy choices including zoning regulations, building codes, and environmental laws. Integrating BIM and GIS gives a digital twin of the urban environment, so enabling governments to model different planning alternatives and make future city improvement evidence-based choices.

Integrating BIM and GIS in urban design helps to produce more resilient, effective, and sustainable cities. Whereas BIM is mostly concerned with the comprehensive design and control of particular structures, GIS gives a spatial framework that undergirds city and regional scale planning. Together, these technologies let urban planning be more comprehensive and assist wise, well-informed decision-making throughout all phases of development of a city [20]. Accordingly, different case studies were studied in the field of utilizing BIM and GIS technologies for urban planning, where three case studies were selected to be presented in the research: one for Infrastructure Planning and Optimization, one for Transportation and Mobility Planning, and one for Energy Management and Sustainability. It is also important to note that each of these selected case studies, includes within its application other aspects such as; Land Use and Zoning, Integrated Urban Development and Design and Smart Urban Governance.

6.1. District in New Cairo, Egypt

A district in New Cairo has been selected for a case study modelling [22], with the aim of creating a framework that supports the prediction, calculation, and visualization of land use data and the associated resource consumption patterns for freshwater, sewage capacity, and electrical energy. It also considered how the city's need for these facilities could be affected by developments in land use or building plans. With regions ranging from 210,000 to 966,000 square meters, the district covers six square kilometres and consists of five land plots (Fig. 4). Along with some vacant spaces intended for future growth, these plots include a hybrid of administrative, commercial, and residential constructions. First, a land breakdown is created. Second, BIM models of all the buildings in the district are created and linked to the respective location on the map using GIS. The parametric dimensions of the completed and unfinished buildings are exported to the created models. A conceptual BIM model is then created with the maximum permitted built-up area with respect to each unplotted property with a pre-established land use. It is thus easy to predict the trends of maximum consumption. Furthermore, both the modelled and the non-modelled plots are given specific building and land codes. Next, the models are associated with the respective sites on the GIS map of the subject area. These buildings or plots are then mapped to the respective territories and districts based on their positions on the map. The limitation of horizontal expansion in BIM models can be overcome by using GIS maps. The buildings in the subject area are then referenced in an external database. Raw and derived data are both included in the database.

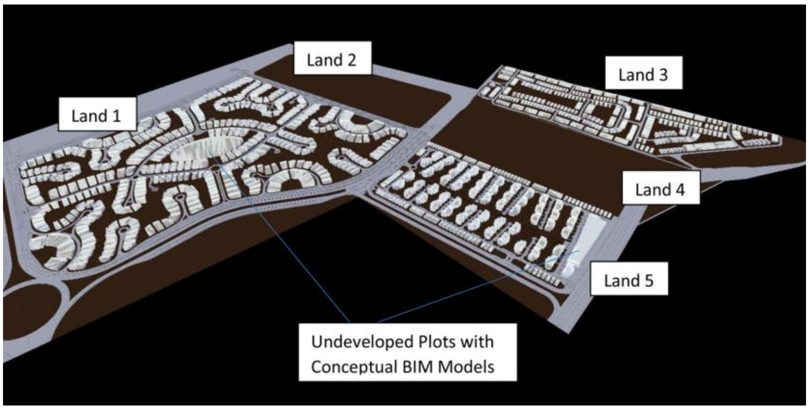

Fig. 4: Developed Models for Five Land Plots [22]

The recommended development scenarios range from altering the type of buildings in existing projects to constructing new facilities or adjusting the development schedules for certain buildings. Among the primary characteristics that distinguish these scenarios are increases in built area, modifications to the purpose of the project, and adjustments to the dates and deadlines of development. These scenarios help evaluate how well the model can support several development schedules and change the resource consumption habits correspondingly.

This is how the scenarios are displayed (Fig. 5):

- **Original Scenario**: Lands 1 and 5 are developed, featuring a mix of residential, administrative, and commercial buildings.
- **Scenario 1**: Land 3 is developed together with lands 1 and 5, with mostly residential buildings and one administrative building. A modification in the development plan is also applied.

- **Scenario 2**: The same lands as in Scenario 1 are developed, but with a change in the usage of some buildings on land 5, switching from residential to administrative.
- **Scenario 3**: Land 4 is developed, building upon Scenario 2.
- **Scenario 4**: Land 2 is developed, further expanding on Scenario 3.

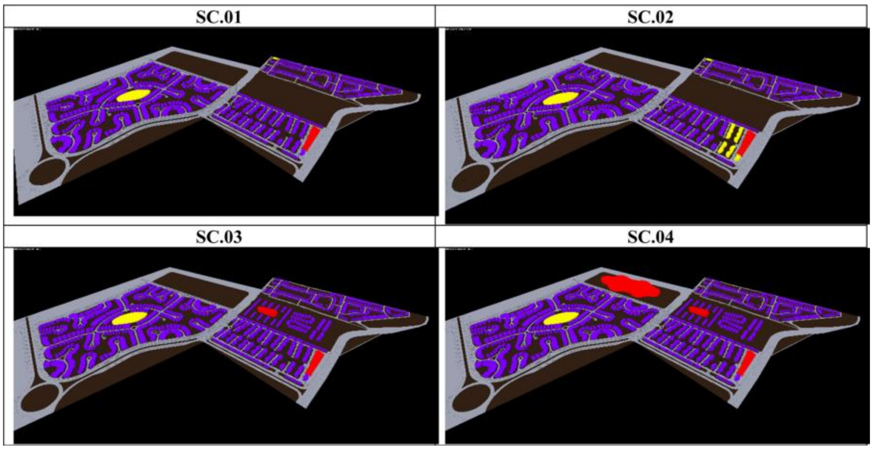

Fig. 5: The Simulation of the Four Scenarios [22]

Accordingly, in order to assess the utility infrastructure demands of the various scenarios, key planned consumptions are plotted (Fig. 6).

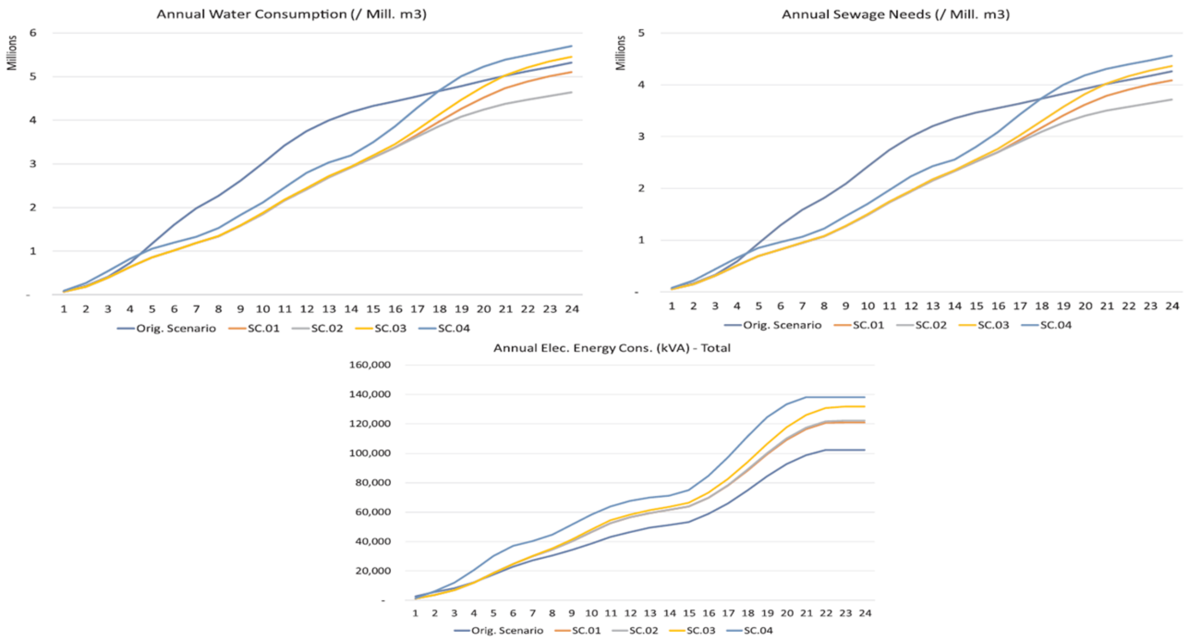

Fig. 6: Annual Planned Consumption Rates for the Developed Scenarios [22]

The model showed its utility in helping urban planners to make wise choices and in understanding the effects of these choices on the needed water, sewage, and electrical energy capacities by simulating and presenting the many scenarios in the case study. The model also provides a dynamic feature by which planners may forecast future consumption rates based on alterations in land form. Whenever the development plan changes, it automatically adapts consumption patterns in the study region. It is found to be effective in quantifying and showing any other time-dependent metrics linked to the modelled constructions by including BIM, time factors, and several consumption measures. For example, expected traffic and occupancy levels may be measured and displayed [22]. Moreover, connecting the model to real-time information from the utility infrastructure of the study region would help to quantify the difference between expected and real usage patterns, therefore highlighting places where assumptions could be adjusted and improved. By combining information from individual plots to lands and districts, the model helps to improve city-level consumption planning and therefore helps with a more intelligent urban development process.

6.2 Semantic Pedestrian Network in Hong Kong

Hong Kong was used as a representative case of a high-density city with an integrated indoor-outdoor pedestrian network, which plays a vital role in people's daily activities. Accessing built environment data, includes; the physical locations of buildings and detailed information about indoor and outdoor facilities and services which is important for various pedestrians such as visitors, residents, administrators and proprietors [23]. Although the information needed by pedestrians is stored in different digital model files (like IFC, shapefile, CityGML, etc.), these data formats lack a direct query language, and there is no standardized language for querying models across different file formats. As a result, extracting information from these models can be time-consuming and technically complex without a unified information query service. To resolve this, the semantic pedestrian network consolidates data from digital models and utilizes semantic query languages to streamline information retrieval and querying (Fig. 7).

The selected case focuses on developing a semantic pedestrian network by combining BIM and GIS data. It introduces applications for this network, such as information queries, route planning, and risk identification, which might be extended further. The integrated RDF graphs cover a variety of instances from the BIM and GIS datasets with cross-domain ontologies and links among them. This will be a solid and strong knowledge base for pedestrian information services. To show its validation and demonstration, in semantic web technologies, indoor-outdoor pedestrian information services can be developed, covering cross-domain pedestrian queries and integrated indoor-outdoor semantic route planning (Fig. 8) [23]. Such applications are vital in promoting smart city development. Furthermore, the knowledge graph using semantic web technologies has a variety of potentials in order to enhance a set of urban applications concerning integrated indoor and outdoor pedestrian infrastructure. A typical model is walkability assessment, considering an extensive range of information both from indoor and outdoor pedestrian systems. Another application includes the inspection of pedestrian infrastructure, such as sidewalks, ramps, and escalators.

The interoperability between BIM and GIS data on the semantic pedestrian network is the focus of this case study. A number of applications targeting the semantic pedestrian network are developed in case, such as information queries, route planning, risk identifications, etc., which can be easily generalized into other application scenarios. The case has explored actual BIM-GIS data integration for improved information services to support pedestrians. The integrated RDF graphs include a large variety of illustrations extracted from BIM and GIS datasets, cross-domain ontologies, and their interconnections. This outlines the complete knowledge base that is the foundation of pedestrian information services. In order to validate and reveal the prospective of this knowledge base, indoor-outdoor combined pedestrian information services will be designed based on semantic web technologies, covering cross-domain pedestrian information queries and indoor and outdoor integrated semantic route planning. Such applications will contribute significantly in the context of smart city initiatives [23].

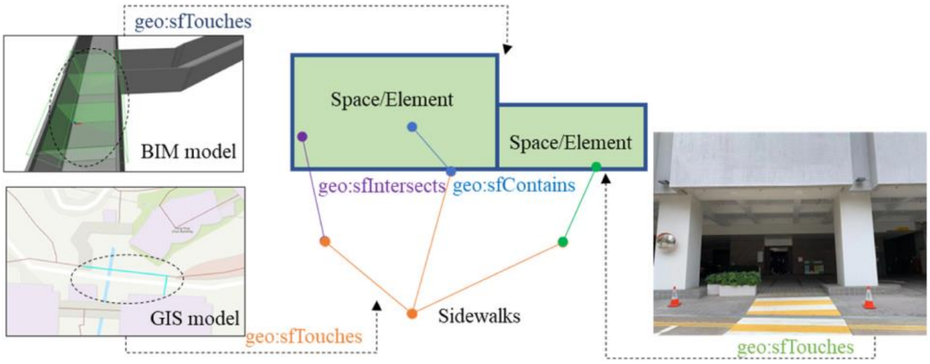

Fig.7: Indoor space/element and outdoor pedestrian route Interconnection Relationship [23]

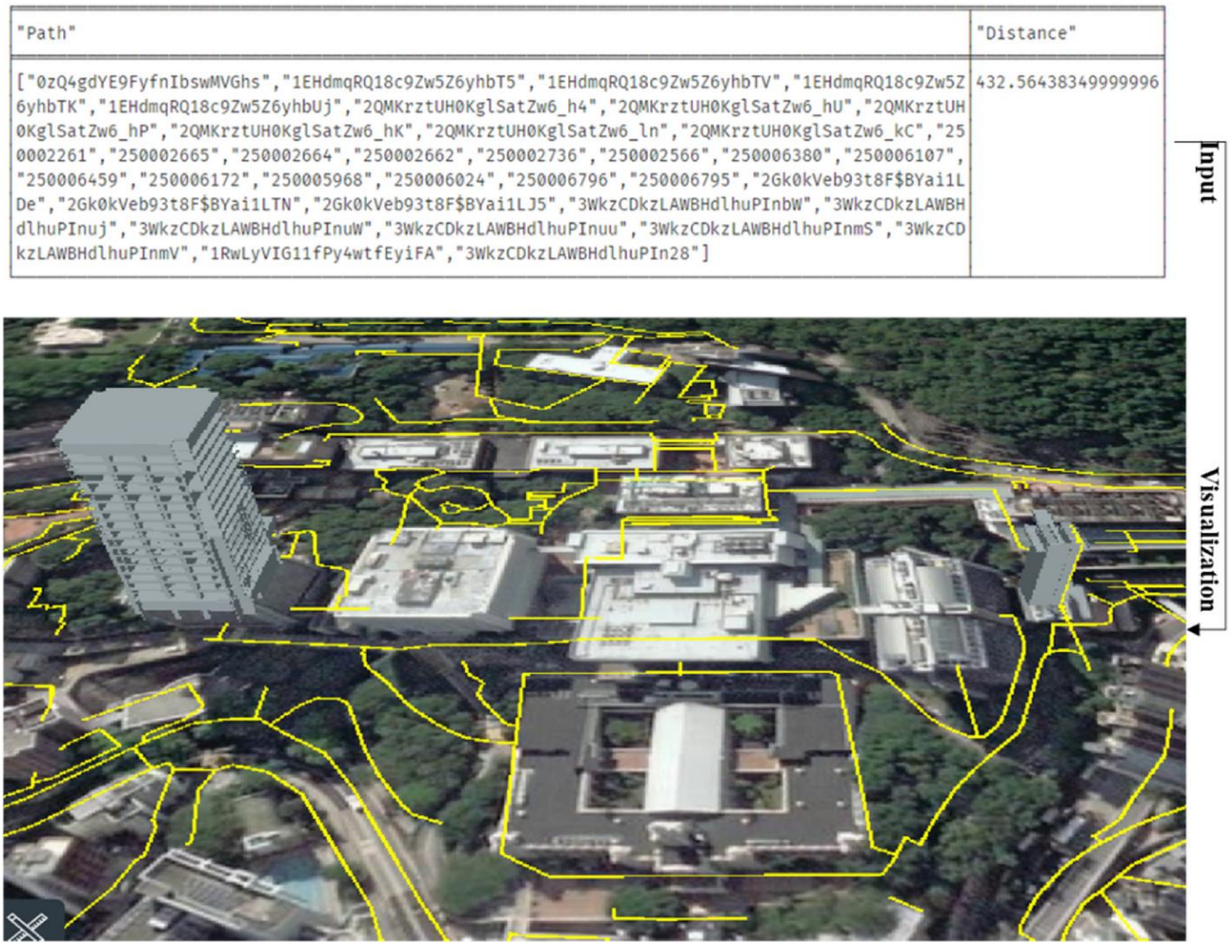

Fig. 8: Results of Semantic Pedestrian Network shown on the 3D Visualization Platform [23]

6.3 Communities around JR Yamanote Line in Tokyo

In order to illustrate the various effects of technology in various locations, the communities surrounding the JR Yamanote line, one of the most significant circular lines in the heart of Tokyo, are adopted as case studies. [24]. A GIS-BIM based urban energy planning tool has been suggested to assist in the planning of smart cities. GIS can represent the real world by layering information and integrating it with geographic locations, allowing for detailed multi-scale, space-time descriptions of communities in attribute tables. In this case study, energy-related data and urban infrastructure are unified through a 3D city model in GIS. BIM focuses on the building scale, providing geometric details and specific building information. The 3D building model created by BIM is positioned within the 3D city model developed by GIS. BIM provides building-level data related to energy performance, while GIS supplies city-level infrastructure data. This integration serves as the foundation for energy demand prediction, which is used in simulations to evaluate the impact of proposed energy policies and technologies. The results for individual buildings are then incorporated back into the city's 3D model supported by GIS. A comprehensive assessment at both the building and city levels is conducted to identify the optimal technology package.

The JR Yamanote line has 29 stations. For the case study, buildings within a 1000-meter radius of each station, across 12 Transit-Oriented Development (TOD) communities, are selected as the target area. These communities include all the target buildings, with no overlap between communities (Fig. 9). The total number of buildings in these 12 communities is approximately 150,000. The building point data from urban planning, which includes information on location, building type, and building area, is used. All selected buildings are distributed and analyzed within 100-meter grids, resulting in around 17,000 grids for the entire target area.

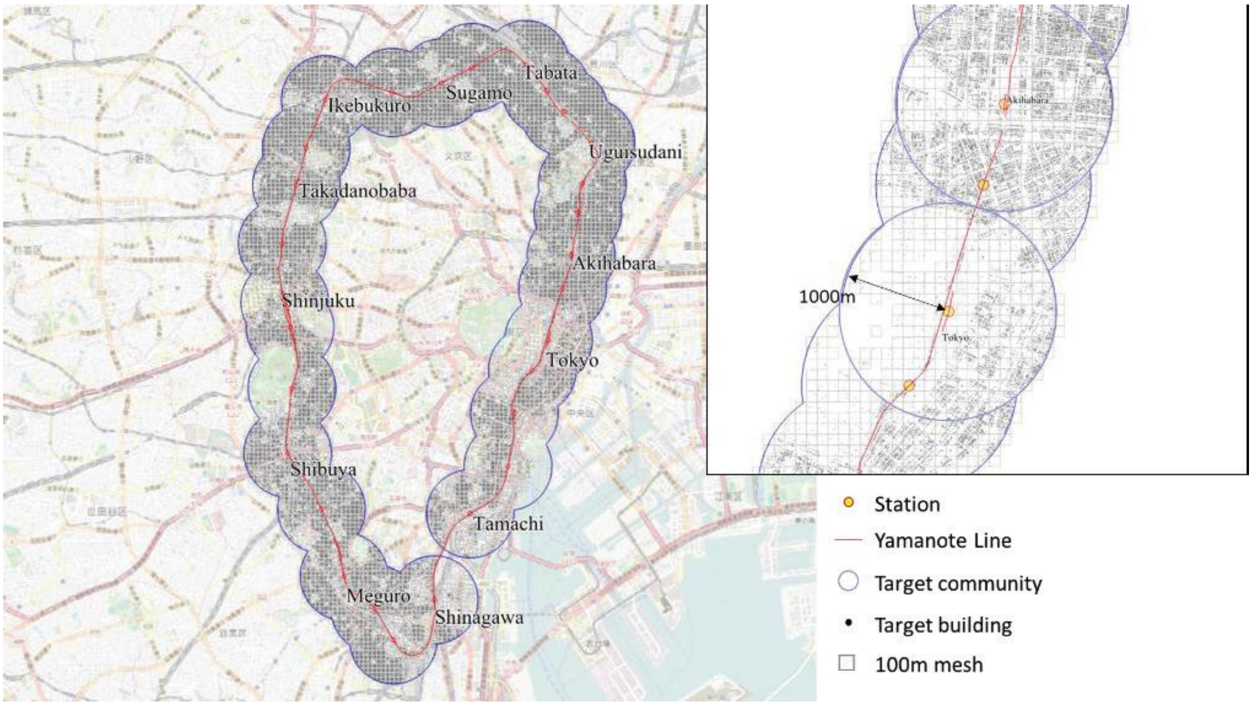

Fig.9: Target Buildings around JR Yamanote Line [24]

The community's current yearly energy usage is displayed using 3D modeling, and three proposed cases were evaluated to compare their energy conservation effects, listed in Table 1. Accordingly, Fig. 10 illustrates the annual energy consumption and energy-saving impact in the target communities. The results indicate that the large-scale development priority model is more effective in communities with a higher concentration of large buildings. In contrast, the long-tail method yields better results in other communities. The energy savings at the city level also show that the greater the use of the long-tail method, the more significant the overall energy savings at the district level. This approach is especially effective in local cities.

Table 1: Case Settings for Buildings around JR Yamanote Line [24]

Cases	Description
Case_1: Large-scale development priority model	Over 60% energy-reduction renovation in case over 50000m^2
Case_2: Long tail method_1	Buildings above 50000m^2 rehabilitated to 20% energy reduction Buildings under 50000m^2 altered lights to LED and used High efficiency air-conditioners.
Case_3: Long tail method_2	Half of the buildings over 50000m^2 rehabilitated to 20% energy reduction Buildings under 50000m^2 altered lights to LED, used High efficiency air-conditioners and installed energy controls

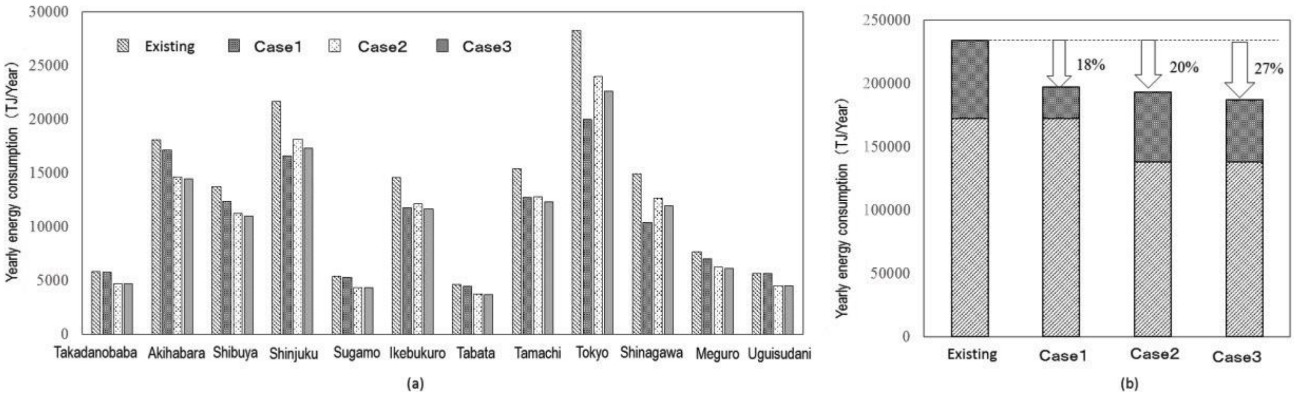

Fig. 10: Annual Energy Saving Effect [24]

7. Integrated BIM and GIS Framework

Based upon the insights gained from the three above mentioned case studies on BIM and GIS integration for urban planning, the comprehensive framework represented in Fig. 11, refines the application of these technologies in urban development projects. The framework provides a structured approach to integrate **Building Site Context with the Environment**, which involves assessing both the physical characteristics of buildings and their relationship to the surrounding environment. This will facilitate the work of planners in predicting what effect a new development may have on a local ecosystem, access to water and sewage, electricity, and overall environmental sustainability. Besides, the framework allows for informed decision-making with regard to various site-specific circumstances, such as topography and climate, conditions of accessibility, and infrastructure development, which permits urban growth more adaptable to ecological concerns.

In the context of the **Semantic Pedestrian Network**, the framework allows for the creation of an interconnected urban space where pedestrian movement is optimized using a combination of BIM's detailed architectural models and GIS's geographic data. This will help planners design safer and more efficient pedestrian routes while considering factors such as foot traffic, accessibility, and emergency response routes. The framework enables real-time data collection and analysis by using semantic modeling, thus helping planners to anticipate future pedestrian needs and improve urban mobility.

The **Energy Performance Maps** component of the framework provides a powerful tool for urban energy management. By integrating BIM's detailed building performance data with the spatial analysis of GIS, planners can create highly accurate energy consumption profiles at both the building and neighborhood levels. This information not only serves to identify high-energy consumption areas but also forms the basis for designing energy-efficient infrastructure, renewable energy solutions, and policies to reduce the urban carbon footprint. Furthermore, this allows the simulation of various strategies for energy savings in different zones of the urban area, creating dynamic and adaptive planning that guarantees maximum energy efficiency in the entire urban landscape. This integrated approach, which spans building-scale analysis to city-wide planning, facilitates smarter urban development that considers long-term sustainability, resource conservation, and improved quality of life for city residents. By bringing together BIM's detailed building data with GIS's spatial intelligence, the framework provides urban planners with a dynamic, data-driven tool that enhances decision-making, enables proactive solutions, and fosters a more sustainable urban future. This framework can be adapted to a variety of urban contexts, offering a scalable model that can be applied to cities of varying sizes and complexities, ensuring that urban planning remains responsive to evolving challenges and opportunities.

8. Discussion and Conclusions

With both BIM and GIS integrated within a single integrated data-driven methodology in urban planning, a new frontier in effective decision-making for enhanced resource utilization will form a backbone toward achieving sustainability in cities. The analysis of the three case studies revealed significant advantages in applying these technologies across different urban contexts. In particular, the framework's application in the Building Site Context with the Environment demonstrates how combining BIM's detailed building data with GIS's spatial analysis capabilities allows for a more thorough assessment of a site's environmental impact. This integration helps ensure that urban developments are optimized not only for economic and social needs but also for environmental sustainability, reducing negative impacts on ecosystems and resources.

Integrated BIM and GIS Framework for Urban Planning					
Data Collection	Urban Related Data		Stakeholdes' Requirements	Building Related Data	
	− Landuse − Energy Infrastructure − Utility Supply (Water, Gas, Sewage) − Transportation Infrastructure (Road, Railway)			− Climatic Data − Building Geometry − Occupancy data − Occupant Activities − Construction Materials − Equipments − HVAC − Lighting	
Type of Application	BIM		&	GIS	
	DESIGN & BUILD			PLAN & OPERATE	
Building Site Context with the Environment Designing and Building In-Context	Infrastructure & Buildings; Roads, Railways, ports, airports..etc	Technical Design Model is developed	IFC BIM & GIS	Spatial Data needed for the environmental impact assessment	SHP files to perform specific analysis
	IFC are done and the SHP files of the spatial data are drawn up it is possible to make the BIM models interact with the GIS data				
Semantic Pedestrian Network	Digital Models	Linked Data	BIM/GIS Data Schema	Digital Models	Linked Data
	Building Information Models	IFC Building Data to Linked Data - RDF		Geospatial Data Models	CityGML Shapeefile Geospatial Data to Linked Data
	Cross-domain Ontologies; Establish connections between Domain Ontologies				
	LBD Ontologies		Ontology Editor	LGD Ontologies	
	Query and Rule Language; Semantic Queries and Inference Rules				
	Knowledge Graph; Interlinking between cross-domain RDF instances to aquire a semantic pedestrian network				
Energy Performance Map	Preliminary Design	Detailed Design	Data imported from BIM to GIS	Managing Data	Energy Regulations
	Data Collection: Location, orientation, weather, materials, space loads, HVAC system..etc	All the required drawings; architectural, civil and electro-mechanical to develop 3D building model in BIM		Data related to; energy consumption and electricity bills	Review the energy regulations; codes and practice
	Energy Simulation	Building Alternatives		Energy Analysis	Energy Masterplan
	Perform Energy Simulation, operational cost, heating or cooling loads, electricity cost and carbon emissions	Application of different scenarios to reach an optimum solution based on specific parameters		Perform analysis and queries to produce energy maps at district and city scales, defining places with high and low energy consumption	Produce energy maps at building, district, and city scales

Fig.11: The Proposed Integrated Framework for BIM and GIS in Urban Planning

Similarly, the Semantic Pedestrian Network shows how integrated BIM and GIS data can make urban mobility more efficient. This system provides planners with an efficient way to manage pedestrian infrastructure, analyze foot traffic patterns, and enhance public safety. The semantic data applied within the framework enables it to dynamically update the system and become an adaptive planning tool providing flexibility for a city to respond to the changes in demand and behavior created by pedestrians. This aspect of the framework is especially crucial in cities experiencing rapid growth or changes in population density, where efficient pedestrian planning is necessary to support a high quality of life.

The Energy Performance Maps component of the framework is one of the most valuable aspects of the integration, especially as cities strive for energy efficiency and carbon neutrality. By combining the energy consumption data from BIM with GIS's spatial modeling, planners can create detailed, actionable energy maps that not only help identify high-consumption areas but also provide insights into how different urban zones can be optimized for energy conservation. This approach supports sustainable building practices, promotes the use of renewable energy sources, and helps cities meet their climate goals by reducing overall energy consumption.

However, the integration of BIM and GIS is not without its challenges. One of the key barriers to successful implementation is the need for standardized data formats and seamless interoperability between various data systems, in addition to, updating urban legislation and legal frameworks. While BIM and GIS offer immense potential when integrated, the lack of universal standards across different platforms can lead to data inconsistencies and complicate the integration process. Additionally, the complexity of combining large-scale geographic data with detailed building information requires advanced technical skills and resources, which may not be readily available in all planning departments. Therefore, the successful adoption of this framework may require significant investment in technology, training, and the development of new standards for data sharing and collaboration across different stakeholders.

Finally, it introduces a new modern and powerful framework of urban planning integrated with BIM and GIS that could have a series of advantages regarding resource efficiency, environmental sustainability, and improved decision-making. Application of the proposed framework in the analyses at the building site, optimization of the pedestrian network, and mapping of energy performance proved highly effective in tackling critical issues related to urban planning. Given this extensive data-driven approach, urban planners can now develop resilient, efficient, and sustainable cities. Despite the challenges in data interoperability and technical complexity, the benefits accruable from an integrated approach far outweigh the disadvantages. It is expected that BIM-GIS integration into urban planning could be the first step toward smart cities, capable of managing resources, reducing impacts on the environment, and increasing citizens' quality of life. These are the issues that, as cities expand and begin to face increasingly challenging futures, will no longer be niceties but will be fundamental in shaping those futures. And as data standards continue to develop and the technical capabilities keep on evolving, this integrated framework will be a really valuable tool for urban planners all over the world.

With the integration of Building Information Modeling (BIM) and Geographic Information System (GIS), sustainable city development can highly be achieved. A data integration platform that combines both BIM and GIS can support the city in urban development, resource management, and even environmental impact assessment. Simulation and real-time monitoring systems can be utilized to evaluate environmental impact beforehand as well as monitor urban processes and infrastructure in real time. With the adoption of these systems, cities can improve sustainability and efficiency in urban development resulting in more livable megacities. Further research can be directed at new business approaches integrating BIM and smart cities such as the sharing and circular economy and digital platforms for resource sharing, conservation, and environmental protection.

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