Smart Integration of Information Technologies for City Digital Twins

Tetyana Honcharenko[1], Volodymyr Khrolenko[2], Ievgenii Gorbatyuk[3], Mariia Liashchenko[4]
Kyiv National University of Construction and Architecture
Kyiv, Ukraine
goncharenko.ta@knuba.edu.ua[1], khrolenko.vm@knuba.edu.ua[2],
gorbatiuk.iev@knuba.edu.ua[3], liashchenko_ma@knuba.edu.ua[4]

Nataliia Bodnar
Al-Rafidain University College,
Baghdad, Iraq
natalia.bodnar@ruc.edu.iq

Noora Hani Sherif
Al-Turath University College
Baghdad, Iraq
noura.hani@turath.edu.iq

***Abstract*—Background: With rising urbanisation and shrinking undeveloped areas, the role of city planning has reached new heights. Incorporating current information technology into city administration provides a path ahead, and the notion of digital twin cities appears as a possible alternative for effective urban planning.**

Objective: The core objective of this study is to describe the process of constructing city digital twins using modern information technology. Understanding and depicting the transition from essential Building Information Modeling (BIM) to sophisticated City Digital Twins (CDT) is required.

Methods: A thorough six-IT-level pyramid is introduced to represent this progression. Beginning with BIM, the model proceeds to incorporate BIM-enabled GIS simulations, Internet of Things (IoT), integration of BIM with Big Data, and Artificial Intelligence, culminating at Level 6 as City Digital Twins. The possibility and technique for developing a CDT information system integrator are also considered.

Results: The combination of the IT mentioned above creates comprehensive digital twins for specific buildings and urban areas. This helps with effectively maintaining these buildings and lays the way for the larger goal of smart cities to be realised.

Conclusion: The current study highlights the need for a systematic, technology-driven approach to urban planning. The incorporation of sophisticated IT into city planning, namely the notion of City Digital Twins, emerges as a critical instrument in the design and administration of future smart cities.

I. INTRODUCTION

The steady expansion of urbanisation and the gradual reduction of undeveloped land have made urban planning increasingly difficult. Urban planners have to work within the limits of a current city while trying to solve problems caused by the growth of cities [1]. Finding uninhabited land in or near the city is challenging, but such land has much promise to improve the whole area. The general potential of the city can be increased by making the right changes to the built world as it is now. So, the land is the city's most important resource and needs to be taken care of with great care. General planners' main job is to find the best ways to organise land so that cities can get the most out of their surroundings. This job is still essential because it involves digitising the city as a whole system [2].

The idea of city information modelling can help urban building and city management in a big way. However, as seen in earlier works, the usual way to make a digital twin of a city was to focus on making digital models of the city's landscape and other spatial items. As information technology moves quickly forward, there are more and more demands for digital models to look right and have the proper physical and meaningful data [3].

Project models mostly show the buildings that will be built and the land around them. These models are used for architecture, design, and general planning. They are as detailed as possible to look like the future built environment [4].

In the form of a satellite information system, existing models give an outline of urban planning items that are already in place. They lay the groundwork for getting design models to study how different parts interact [5].

Urban planning is a complicated process that controls how a city grows. Urban planners have to deal with many things, such as collecting data, analysing it, making predictions, evaluating it, setting goals, and talking to the public. To use IT to solve urban planning problems successfully, it is crucial to map the current urban environment, combine it with planned design changes, and predict how the results will affect the parts of the existing urban system. It is a valuable tool for organising the city's resources and dealing with the problems that come with the complexity of urban processes. It helps people make decisions by giving them different options for solving problems and showing how well-tested urban planning ideas work [6].

The study explores the potential of employing multidimensional data models for urban area computer modelling in development. Existing research demonstrates the efficacy of integrating spatial information to address territorial planning challenges. The urban environment comprises intricate elements encompassing static environmental models and dynamic urban construction components. This results in a substantial volume of information generation. However, the value of this information depends on its ability to contribute meaningfully to the system. Given the information age's proliferation of data, selecting high-quality data sources for informed decision-making becomes paramount. Effective data extraction from this vast pool necessitates a prior organisation of information.

This article's primary objective is to engage in research and development concerning the components of City Digital Twins (CDT). It is achieved through the intelligent integration of contemporary information technologies to analyse data about cities and their urban landscapes.

II. Literature Review

City Digital Twins (CDTs) is an innovative, advanced urban planning and administration method. Virtual copies of real-world cities facilitate data-driven decision-making, predictive analytics, and enhanced urban governance. The successful implementation and optimal exploitation of CDTs are contingent upon the intelligent integration of diverse information technologies. This literature study examines significant research and advancements in incorporating information technology within the framework of City Digital Twins.

The gathering and integration of multiple data sources are essential aspects of CDTs. Sensing technologies, including Internet of Things (IoT) devices, satellite imaging, and crowd-sourced data, are necessary to collect data. Scholars have highlighted the need to implement robust data integration frameworks to manage data originating from diverse sources [7] effectively. These frameworks facilitate the maintenance of data accuracy and dependability, allowing the development of a dynamic virtual representation of the urban environment.

Geospatial Information Systems are computer-based systems that capture, store, manipulate, analyse, and present geographically referenced data.

Geographic Information System technologies allow the examination and depiction of data in a geographical context, a vital aspect in developing a precise virtual portrayal of the urban landscape. Scholars have investigated integrating GIS data with real-time sensor data to augment the precision of Cyber-Physical Systems known as Cyber-Physical Digital Twins (CDTs) [8]. The integration of this system enables urban planners and decision-makers to get valuable knowledge about many spatial dimensions of the city, including transportation, land use, and environmental variables.

Building Information Modeling significantly transforms the construction and design sectors by digitally depicting building procedures and data. It is essential to strategically integrate information technologies to use the capabilities of BIM [9] fully.

Data integration and interoperability refers to the seamless combination and compatibility of many datasets and systems. It involves harmonising and consolidating data from different sources, allowing for efficient and effective sharing and analysis [10].

Building Information Modeling encompasses a diverse range of stakeholders, each responsible for creating and using distinct forms of data. The smooth interaction of different data sources is crucial for the successful implementation of the project. Scholars emphasise the need for open standards and protocols to attain data interoperability [11]. These standards provide efficient information flow across software programs, promoting project participant cooperation.

Integrating BIM with GIS constitutes a potent synergy that amplifies spatial comprehension and analysis. Scholars have investigated integrating geospatial data into Building Information Modeling models, aiming to enhance the processes of site selection, environmental impact assessment, and urban planning [12]. Combining Geographic Information Systems with BIM provides a comprehensive perspective on building projects and their wider environmental surroundings.

Artificial intelligence (AI) and machine learning (ML) technologies are being rapidly used in the field of BIM to facilitate predictive analysis and provide decision assistance. These technologies possess the capability to discern patterns within construction data, forecast potential project delays, and enhance the allocation of resources. As an example, artificial intelligence algorithms have the power to evaluate project risks via the examination of past data and the identification of possible obstacles [13]. Machine learning models play a crucial role in automating laborious processes such as collision detection, leading to error reduction and time savings.

Cloud computing has significantly transformed the BIM field by facilitating the development of secure, scalable, and collaborative platforms. Cloud-based Building Information Modeling technologies enable seamless and instantaneous communication across all parties involved in a project, regardless of their physical locations. Scholars have investigated how cloud-based BIM platforms enhance project collaboration and mitigate issues associated with data management [14]. These systems provide the necessary adaptability for extensive initiatives with intricate data prerequisites.

Using proficient visualisation tools is imperative in effectively conveying BIM data to various individuals involved in the building process, including architects and construction workers [15]. Augmented Reality (AR) technology improves on-site decision-making processes by integrating Building Information Modeling data into the accurate building site. Scholars have directed their attention to the advancement of AR apps that enable users to see building information modelling models inside real-world environments [16]. This technology optimises building procedures and mitigates inaccuracies.

III. Method

A typical workflow of information processing by an automated system using software consists of procedures: collection, input, storage, processing, analysis, and obtaining the result. Creating a City Digital Twin is similar to this typical process. Fig. 1 shows the City Information Environment concept for Digital Twin based on the construction life cycle [17].

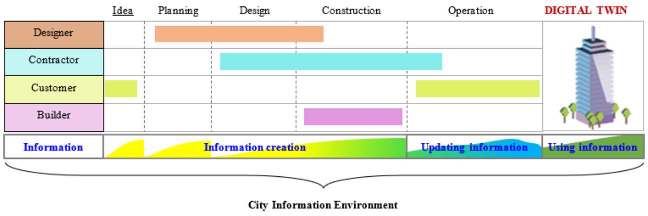

Fig. 1. City Information Environment concept for DIGITAL TWIN based on the construction life cycle

The creation of a CDT should be investigated from the point of view of the life cycle of the construction object. At the design stage, it is advisable to use Building Information Modeling technology to embed information data into the existing city model. At the stages of planning, construction and operation, it is advisable to use, in addition to BIM, GIS and other information technologies for searching, analysing and monitoring information about the future CDT. This approach will contribute to the adequate display of the CDT in the information system and cause it to be filled with up-to-date, reliable and consistent data [18].

In their work, the authors present a six-level pyramid illustrating the progressive evolution from BIM to Digital Twins, depicted in Fig. 2. The pyramid comprises the following levels:

1. Level 1: BIM
2. Level 2: BIM-enabled GIS simulations
3. Level 3: BIM integrated with Big Data
4. Level 4: BIM integrated with Internet of Things (IoT)
5. Level 5: BIM integrated with Artificial Intelligence (AI)
6. Level 6: City Digital Twins.

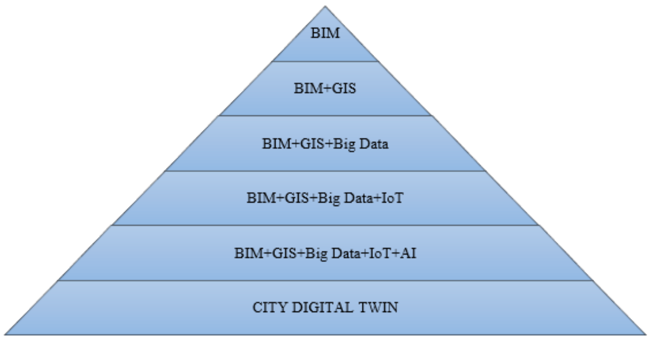

Fig. 2. Evolution of BIM to City Digital Twin

Building Information Modelling is critical in creating City Digital Twins by offering three-dimensional visualisation, coordinating data transmission, and allowing dynamic information optimisation. On the other hand, the GIS is in charge of gathering, storing, managing, analysing, and presenting data connected to the geographical distribution on the earth's surface [19]. This geographic data depicts the link between buildings and their surroundings, allowing for sophisticated, complex spatial analysis [20]. CDT uses GIS to deliver a uniform geographical coordinate system and entire administration and analysis of 2D and 3D data on a broad scale. While BIM focuses on detailed data administration and modelling, GIS focuses on macro data management and urban spatial analysis. Furthermore, GIS is a critical tool for describing the city's macrogeographical spatial environment, supporting the connectivity of individual BIM points in the city's information system [21].

Using big data technologies to analyse massive, complicated data sets addresses the issue. It offers theme frameworks for modifying, assessing, and analysing urban subsystems such as population, transportation, and public services [22].

The Internet of Things helps gather and integrate continuous environmental data streams. It highlights the city's connectivity of people, machines, and things, providing real-time information. CDT transforms from a static depiction to a dynamic perspective of the city's operation using IoT technologies [23].

AI improves data recognition skills by learning and analysing data from various sources, such as government records, company databases, social networks, and the Internet. It allows for more accurate urban growth pattern forecasting, leading to better city planning and administration. The combination of BIM, GIS, Big Data technologies, IoT, and AI creates a whole Digital Twins Concept for Construction projects, enabling efficient levels of integration and communication across various system components [24].

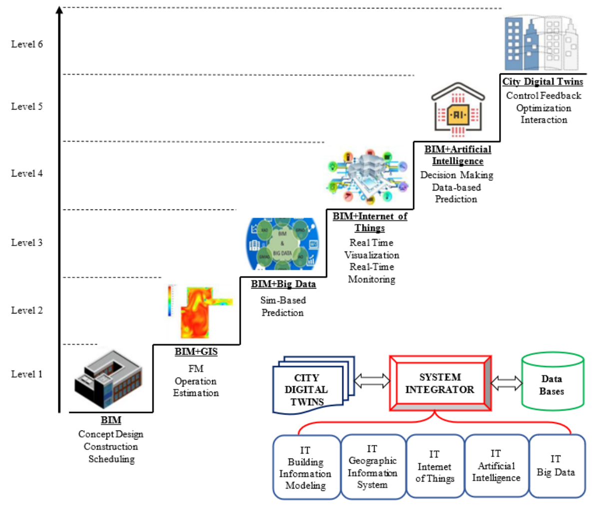

Fig. 3. Digital Twins Concept for Construction project by levels of integration

The use of BIM technology kicks off City Digital Twin's creation. At the same time, GIS supplements the process by providing information about the city's built-up regions, complemented by a wide variety of data from devices which function outside the core BIM workflow [25, 26]. Big Data technologies make verifying and processing these extensive data sets possible. The application of IoT technology allows for dynamic interconnection and monitoring of CDT components [27]. Artificial intelligence systems will provide the ability to recognise and learn the received data based on neural networks [28]. One of the problems with this structure is that data from different information systems is stored mainly in isolation, and connecting it to a standard data environment requires a considerable amount of manual work.

Another problem is related to the origin of the data: how qualified and accurate is the data? Design decisions will always involve risk if data quality cannot be guaranteed. To solve these problems, it is proposed to develop an information system integrator, the conceptual diagram of which is presented in Fig. 3.

IV. Results

In practice, this research finds its application for creating CDT in urban areas using Autodesk software products: Vault, Revit, and Navisworks. We received four input files with spatial and attribute data and placed them in the City Information Environment.

The first central file presents data on the coordinates of the studied territory. The other three files have the same access to the coordinates as the central file and contain data on the objects of urban development located on the studied territory. Fig. 4 shows the City Digital Twin of a real house modelled in Autodesk Revit.

Fig. 4. Digital Twin of city building

Fig. 5. Limits of urban development modelling

Fig. 5 is a part of the plan of the studied territory, which provides information about the boundaries of urban development modelling. Fig. 6 presents three-dimensional models of all urban objects with height reference to the terrain and location on the central file. Fig. 7 shows a digital plan of the urban area. Fig. 8 shows a 3D City Digital Twin of a built-up urban area as an Autodesk Navisworks file.

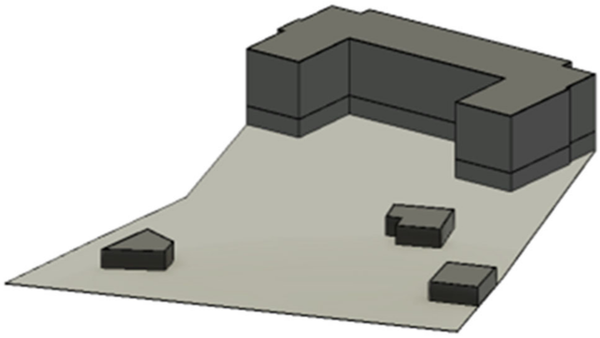

Fig. 6. Locations of city objects

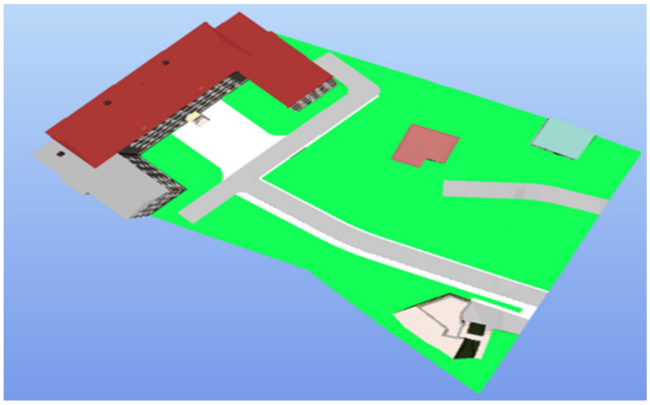

Fig. 7. Digital plan of the city territory

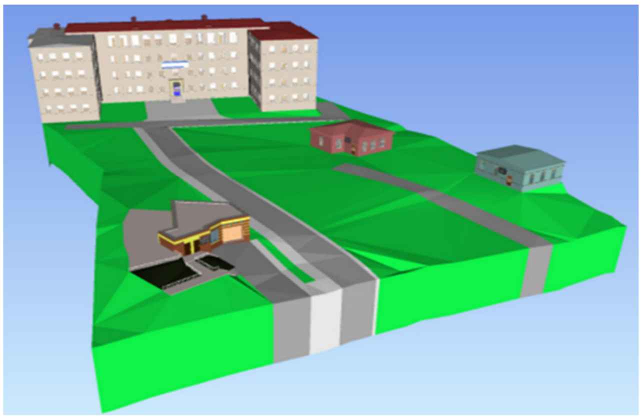

Fig. 8. City Digital Twin of the built-up urban area

V. Discussion

Incorporating information technology into City Digital Twins (CDTs) has attracted considerable interest in recent years, owing to its potential to transform urban planning and development. The current discourse examines the primary discoveries and understandings in the article, using pertinent scholarly works to underscore the importance of CDTs in influencing the trajectory of intelligent urban areas.

The introduction of CDTs signifies a significant achievement in digitally revolutionising urban environments [1]. City Digital Twins are advanced digital models that simulate urban areas by integrating real-time and historical data from many sources. This integration enables a holistic understanding of urban settings. This idea expands upon the principles of BIM, GIS, and other digital technologies to provide a dynamic depiction of urban areas [4], [5].

One of this study's critical contributions is its focus on strategically incorporating contemporary information technology. The significance of intelligent city digital twins in urban planning is emphasised by Mohammadi and Taylor [2]. The abovementioned factors underscore the need to fully use sophisticated data analytics, artificial intelligence, and the Internet of Things to use CDTs' capabilities. This statement aligns with the article's aim to use information technology efficiently for efficient city modelling and analysis.

The authors Shahat, Hyun, and Yeom [3] provide significant contributions to the understanding of the capabilities of CDTs, with a particular focus on their significance in the context of sustainable urban development. The article examines the potential benefits of using CPS, known as Cyber-Physical Digital Twins, in several domains, such as resource allocation optimisation, infrastructure management improvement, and promoting environmentally sustainable practices. The statement aligns with the broader conversation around smart cities, which aims to create urban settings that are both technologically sophisticated and ecologically sustainable [7].

Incorporating BIM into CDTs is a salient facet of this discourse. The significance of Building Information Modeling in the construction sector is underscored by Chen et al. [8]. Furthermore, the integration of BIM into CDTs introduces a novel aspect to the field of urban planning. Building Information Modeling enables the creation of detailed models for specific buildings and infrastructure elements, permitting accurate simulations inside the digital twin [11]. The paper appropriately recognises the role of BIM in enhancing the precision and level of detail in CDTs.

Additionally, the paper discusses the notion of Edge Computing [10], which plays a crucial role in processing data collected from diverse sensors and devices integrated throughout the urban environment. The capacity to interpret data in real-time is vital for CPS to provide timely and current information to those responsible for making decisions. Edge computing technology improves the timeliness and dependability of CDTs, increasing their effectiveness in urban government [26].

The debate highlights the transdisciplinary character of CDTs. The holistic approach to urban management is achieved by integrating principles derived from urban planning, data science, engineering, and computer science. This observation is consistent with the study conducted by Mylonas et al. [28], which emphasises the wide-ranging uses of digital twins across several sectors. Cyber-physical systems, known as CDTs, can facilitate the connection between professionals in urban planning, policymaking, and technology, promoting collaborative efforts and exchanging information.

The article offers insights into incorporating information technologies to advance CDTs. Through the use of advanced technologies such as BIM [14], IoT, and Edge Computing, CPS can potentially revolutionise urban planning and governance. The extensive scope of CDTs, as emphasised in this discourse, establishes them as a potent instrument for advancing sustainable and intelligent urban development. With the ongoing advancement of technology, Connected and Autonomous Vehicles (CAVs) will probably have a progressively influential role in defining future urban landscapes.

VI. Conclusions

The need to integrate new information technology to produce CDT for successful urban planning and decision-making is highlighted in this article. The suggested six-IT level pyramid shows the evolutionary route for establishing complete digital representations of cities, beginning with BIM and concluding with City Digital Twins.

In order to create information-rich 3D models of cities and their urban settings, BIM and GIS technologies must be integrated. City planners and stakeholders may get a comprehensive picture of the built environment by merging these two technologies, allowing for a greater understanding and study of urban settings.

Internet of Things technology is essential to provide municipal operations data in near real-time. This constant flow of data enables municipal officials to monitor numerous elements of urban life, such as traffic, energy consumption, trash management, and public safety, allowing them to make educated choices quickly.

The collaboration of Big Data with Artificial Intelligence is beneficial in effectively processing massive and complicated data sets. AI systems may process Data from various sources quickly and efficiently, making sense of it and discovering patterns and trends that traditional data analysis may miss. AI may forecast future situations by utilising knowledge from the past and present, assisting urban planners in proactive decision-making.

Experimentation has shown that creating a City Digital Twin for urban development is possible that precisely correlates to its real-world equivalent. The use of CDTs helps the transition from conventional 2D drawings to complete 3D models, which improves decision-making for establishing real estate borders and planning metropolitan regions.

A City Digital Twin helps individual buildings and metropolitan regions and creates the groundwork for smart city implementation. Smart CDTs provide a dynamic and interactive platform for urban administration, allowing administrators to optimise resources, improve service delivery, and improve inhabitants' overall quality of life.

Since they are digital equivalents of tangible assets, CDTs are essential for modelling perspective changes and their influence on the city's infrastructure and environment. This proactive strategy helps with scenario planning, risk analysis, and catastrophe preparation, reducing possible hazards and establishing a resilient urban environment.

Information technology integration is a transformational force in urban planning and administration. Cities may adopt a data-driven, proactive, and dynamic approach to decision-making by establishing City Digital Twins via the synergy of BIM, GIS, IoT, Big Data, and AI. These intelligent CDTs provide a significant potential to promote sustainable development, optimise resource utilisation, and enhance the general well-being of metropolitan populations. As the digital era progresses, adopting City Digital Twins is essential to developing more intelligent, more resilient, and future-ready cities.

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