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REVIEW ARTICLE

Digital twins and 3D information modeling in a smart city for traffic controlling: A review

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ABSTRACT

The idea of a smart city has evolved in recent years from limiting the city's physical growth to a comprehensive idea that includes physical, social, information, and knowledge infrastructure. As of right now, many studies indicate the potential advantages of smart cities in the fields of education, transportation, and entertainment to achieve more sustainability, efficiency, optimization, collaboration, and creativity. So, it is necessary to survey some technical knowledge and technology to establish the smart city and digitize its services. Traffic and transportation management, together with other subsystems, is one of the key components of creating a smart city. We specify this research by exploring digital twin (DT) technologies and 3D model information in the context of traffic management as well as the need to acquire them in the modern world. Despite the abundance of research in this field, the majority of them concentrate on the technical aspects of its design in diverse sectors. More details are required on the application of DTs in the creation of intelligent transportation systems. Results from the literature indicate that implementing the Internet of Things (IoT) to the scope of traffic addresses the traffic management issues in densely populated cities and somewhat affects the air pollution reduction caused by transportation systems. Leading countries are moving towards integrated systems and platforms using Building Information Modelling (BIM), IoT, and Spatial Data Infrastructure (SDI) to make cities smarter. There has been limited research on the application of digital twin technology in traffic control. One reason for this could be the complexity of the traffic system, which involves multiple variables and interactions between different components. Developing an accurate digital twin model for traffic control would require a significant amount of data collection and analysis, as well as advanced modeling techniques to account for the dynamic nature of traffic flow. We explore the requirements for the implementation of the digital twin in the traffic control industry and a proper architecture based on 6 main layers is investigated for the deployment of this system. In addition, an emphasis on the particular function of DT in simulating high traffic flow, keeping track of accidents, and choosing the optimal path for vehicles has been reviewed. Furthermore, incorporating user-generated content and volunteered geographic information (VGI), considering the idea of the human as a sensor, together with IoT can be a future direction to provide a more accurate and up-to-date representation of the physical environment, especially for traffic control, according to the literature review. The results show there are some limitations in digital twins for traffic control. The current digital twins are only a 3D representation of the real world. The difficulty of synchronizing real and virtual world information is another challenge. Eventually, in order to employ this technology as effectively as feasible in urban management, the researchers must address these drawbacks.

Keywords: Digital Twin; Transportation; GIS; BIM; Route Finding; Data Sharing; System Architecture

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1. Introduction

The cities are facing challenges with the expansion of urbanization and the growing trend of the urban population that cannot be solved with traditional methods. In recent years, with the growth of technology, big cities in the world using the Internet and technology have provided different services and urban life to their citizens. In this way, "Smart Cities" emerged. A smart city is a metropolitan area that uses various electronic sensors to collect and analyze information. This information is functional in the efficient management of city assets and resources. The process of a smart city creation includes the collected data from citizens, devices, and urban resources, which is processed and analyzed to help to monitor and manage the traffic and transportation systems, power plants, water resources, garbage, implementing information systems, schools, libraries, hospitals, and other social services[1]. In smart cities, which use Information and Communication Technology (ICT) and the Internet of Things (IoT) to administer cities, citizens face minor challenges in their daily lives. IoT solutions based on cloud computing receive and analyze the citizens' information and provide it to city managers so they can take the necessary measures to manage citizens' challenges. Various devices are connected to the Internet of Things (IoT) network to optimize the efficiency of urban services and uses and connect it to citizens. Smart city technology allows city officials to interact directly with the community and urban infrastructure and what is happening and evolving[2].

Applying outdated, inefficient systems is not taken into consideration in today's congested and populated societies, which are taking into account the growth and population of the cities as well as the limited energy and economic resources. That's why, in the scope of transportation and traffic, which is one of the development and advancement indicators of cities, controlling and managing transportation networks is difficult by traditional methods. In this respect, efforts were made to bring enormous investments in technology and its related fields for increasing the efficiency of public transport and traffic control[3], which becomes the subject of this review. Making the city smart is a complex process due to the complexity of a city. A city is not an automatic system quickly understood and predicted but a living system that evolves through changes and transformations in physical structures, economic and political activities, social and cultural settings, and ecological systems every day[4]. Digital twin (DT) and Building Information Modelling (BIM) are recognized as contributing to increasing cities' environmental and economic sustainability and improving the provision of services to their residents[2]. Building Information Models (BIMs) are digital data that may be retrieved, distributed, or networked to assist decisions about constructed assets including buildings, roads, railroads, bridges, and other urban utilities[5].

BIM is a process involving the generation and management of digital representations of physical and functional characteristics of physical product or construction, while digital twin refers to a digital replica of physical phenomenon, assets, processes, or systems that can be used for various applications. As BIM is an effective tool for generating digital representations of physical products or constructions, it is just one method for creating digital twins.

One of the most paramount methods are BIM-based methods focusing on building fields. BIM has a key role to generate such a DT whose dynamic performance can be studied by building simulation tools for a variety of different boundary conditions. When it comes to a city scale, in addition to those capabilities required in community-scale digital twins, tracking the mobility of individuals is another important required capability. As citizens commute frequently across a city by transportation systems, urban systems such as traffic and energy and their associated interplay play a significant role in achieving smart cities. By understanding how citizens move across a city, urban planners and policymakers can make informed decisions about transportation infrastructure, energy usage, and other aspects of urban management. Therefore, BIM is just one example of the application of digital twin technology in the AEC industry; but BIM is neither the main character to generate a digital twin nor the best methodology to establish digital twin technology. There are different methods to create digital twins in different parts of smart cities, like the road network, telecommunications facilities, power transmission lines and buildings[6,7].

The digital 3D city model constitutes a large digital ecosystem comprised of multiple linked sources of data. Accordingly, a physical product or construction, a digital representation of that, and the bidirectional data links that transfer and the bidirectional data links that transfer information and processes from the virtual representation to the real object are the three elements that make up a digital twin[8]. One of the major applications of DT in a city scale is reflecting the whole domains and systems of the city on a digital platform that causes the improvement of city visibility, realization, and performance; therefore, it guides the development of the smart city. The digital twin of the city is expected to improve urban management and operations to achieve a more intelligent and sustainable city and a higher quality of life for its citizens[9–11].

The development of mutual integration between the digital and physical counterparts would bring many benefits to the performance and management of the city. Because establishing a digital design for a physical location reduces several project and construction risks and enhances the system's forecaster capacitance[12].

A variety of management domains have emerged to handle city systems and challenges the smart cities data and intelligent applications need to replicate, as precisely as possible, the state of the city and to simulate possible predictable futures. Data, particularly respecting assets, water, transport, construction projects, environmental quality, wastes, and human resources, is managed at the most basic level.

Therefore, the intelligent modeling of the city should cover all aspects of the real issues relevant to the city requiring smart solutions. 3D models are digital representations of physical space, which are helpful for planning and executing building projects. The important 3D modeling aspects in smart cities include networks and flows that can describe all motion in the city; building, roads and facilities models (historic, present, and future), including all aspects that could impact the city, environment, citizens and activities, capable to support planning and maintenance through 3D models of urban planning, cadaster, and environmental factors[11,13].

Governments have spent a lot of money developing and enhancing their road networks since roads are one of the key components of transportation systems. Since many decisions depend on geospatial information and analysis, adding the spatial dimension increases the efficiency of each transportation project in the design and construction process. By incorporating geospatial data into transportation projects, governments can make better decisions about where to allocate resources, how to optimize routes, and how to improve overall transportation efficiency. Regarding the capabilities of GIS in storing, visualizing, managing, and analyzing georeferenced data, along with communicating with 3D information modeling through BIM-based technology and collecting environmental information using online sensors can make this platform as a core to handle urban management and transportation projects[14]. By integrating BIM-based technology and online sensors, GIS can provide real-time information about the environment and infrastructure, which can be used to optimize project localization and routing. Additionally, GIS can be used as a monitoring tool to detect and manage accidents and crises such as road accidents. Smart traffic control is an essential component of smart city plans because traffic congestion is a severe issue that grows with city development. A smart application may use real-time traffic data to alert drivers and announce public transport delays. Smart traffic management includes intelligent transportation systems with integrated elements such as adaptive traffic signal controls, freeway management, and emergency and roadside unit's services[15]. By using real-time traffic data, smart traffic applications can help drivers and public transport users make more informed decisions about their travel routes and schedules, reducing congestion and improving overall traffic flow. Intelligent transportation systems, such as adaptive traffic signal controls and freeway management, can also help to manage traffic more efficiently, reducing delays and improving safety[16].

Perception of the movement patterns of vehicles at the city roads level affects transportation planning and operations and it can make them more efficient and service-oriented. Transportation and traffic congestion can be dynamically updated or estimated in digital twin taking real-time traffic data from IoT, analytic tools, cloud computing, the new generation of networks, and artificial intelligence[17]. The purpose of a traffic congestion control and management system is to resolve traffic congestion in the shortest possible time, open the way for vehicles, and determine the shorter length routes for vehicles[18,19]. Initial planning choices on a traffic project's viability and sustainability can be inspired by BIM, and it can also serve as a pre-construction guideline. Additionally, 3D visualization and embodiment for DTs may be provided via BIM technology[5].

The traffic planners or engineers can easily simulate the traffic conditions and flexibly play with the planning scenarios under different circumstances with BIM platform, as they are accurate as-planned building digital models attached with all sorts of properties. BIM can help traffic planners and engineers to simulate traffic conditions and plan scenarios under different circumstances by creating accurate 3D models of buildings and their surroundings. This can help in identifying potential traffic congestion points and designing solutions to alleviate them. Beside BIM, GIS has also been tentatively researched to streamline the traffic network design and conduct spatial statistics, considering its advanced capability in spatial pattern analysis under multi-criteria[20].

The ability to monitor traffic conditions digitally and in real-time is a valuable tool for urban planning and management. The 3D visualization capabilities of BIM also make it an effective urban simulation platform for examining different traffic scenarios and making informed decisions about infrastructure improvements. BIM model enables the 3D experience of streets, infrastructure, short and tall buildings, etc. BIM is not only used in road construction but can also be used for traffic, noise pollution, and cost-effectiveness studies. The traffic condition may also be monitored digitally and instantly with the aid of navigation through an online service or internet portal[21]. These features lead to an urban simulation platform that displays a real-time, three-dimensional representation of the city and road network, allowing for quick examination of various traffic situations within that setting[22].

Innovatively presenting cooperative GIS and BIM system framework along with DT in smart cities, despite having distinct conceptions and development phases, under which the statistical data regarding the existing traffic condition can be acquired and the effective traffic planning can be conducted by comprehensively considering the possible impact of the localized traffic flow to the ambient traffic[20]. By combining cooperative GIS and BIM systems with DT in smart cities, it's possible to gather statistical data on current traffic conditions and use that information for effective traffic planning. This approach takes into account the potential impact of localized traffic flow on surrounding traffic, allowing for more comprehensive and accurate planning. The integration of these systems can lead to more efficient and sustainable urban transportation systems.

This paper aims to review the conducted research on digital twin and information modelling with an emphasis on traffic management during heavy traffic flows of the road network.

We also review the systems in which the digital entity is synchronized with the current physical state in simulating the road traffic flows. Other discussed are the achievements of such technology to determine the shortest and fastest route for vehicles in traffic, optimal management of the traffic load, and subsequently improving security and reducing the environmental pollution. However, the growth and development of digital twins are still in their early stages, and there are many various definitions, implementation frameworks, and different protocols in this field.

Existing research requires a thorough and in-depth examination of the digital twin from the standpoint of its ideas, innovations, and uses in smart cities, particularly in the areas of transportation and traffic management. Although a few digital twin studies have been conducted in the transportation domain very recently, there is no systematic research with a holistic framework connecting various mobility entities together[23]. Such a review study is essential because it may guide effective, industry-scale implementations of digital twins for the optimum traffic management systems.

Based on a literature review of over 90 research papers on digital twins through a comprehensive and in-depth review of related researches, this article considers to:

- Analysing the state of digital twin research and 3D information modelling
- Providing a summary on digital twin usage in smart cities and especially in the area of traffic management
- Addressing the critical role of geospatial information in the digital mapping of urban areas for use in road traffic management
- Providing a detailed discussion on the proposed architecture of modelling methods and digital twins
- Eventually, providing potential solutions to solve existing problems using this technology

The challenges and future research directions on digital twins will also be discussed based on the literature survey and lessons learned from case studies.

The research process involves multiple stages, including searching relevant databases and digital libraries for papers, considering their citation statistics, studying the full text of related articles, and classifying them based on specific criteria. This research and review process includes four main stages: (a) search multiple databases and digital libraries and portals such as Science Direct, Springer, Scopus and Taylor & Francis with relevant keywords; (b) search the selected papers in google scholar to consider their citation statistics; (c) study the full text of related articles and classify them based on the specific criteria of this research; (d) deeply analyze the findings based on the characteristics such as study stages, research content, and publication date, then investigate the process development trend, various technologies and applications.

The methodology used in this paper consisted of six main steps. (a) Briefly identification of digital twins' technologies and smart cities in different fields by searching and identifying bibliographic sources of digital twins. (b) In the next section, we analyze the state of research related to the digital twin, its related fields like BIM, and GIS in smart cities, and information modeling and review the past literature. (c) Section 3 devotes to the categorization of digital twin applications in the intelligent transportation system, traffic management, and route finding by searching and identifying bibliographic sources of ITS, IoT, and DTs. (d) Analysis of identified digital twins in urban fields by surveying the input and output of these systems. (e) Surveying and proposal of the urban digital twin structure based on data sharing, and (f) identification of benefits, open issues, and key challenges from the results.

2. A gentle review of digital twin in smart cities

The origin of the digital twin concept dates back to the 1960s when NASA first thought about twinning for its Apollo mission. During this time, early twinning concepts were used in space programs to build actual replicas of their systems on Earth. This idea allowed them to simulate different scenarios, test the various cases and conditions, and evaluate the behavior and performance of their systems. The digital twin concept has gained popularity in recent years due to the advancements in technologies such as IoT, AI, and cloud computing. Over time, until the early 2000s, Michael Grieves introduced the concept of digital twins to the manufacturing industry by creating virtual copies of factories to monitor their processes, predict failures, and increase productivity. This concept gained more attention and greatness after it was listed as one of the top ten strategic technology trends by Gartner in 2017 and was adopted by several industrial giants such as Siemens and General Electric[24,25].

The adoption of digital twin technology in the manufacturing industry has revolutionized the way factories operate. By creating virtual replicas of physical assets, manufacturers can monitor and optimize production processes in real-time, predict equipment failures before they occur, and make data-driven decisions to increase productivity and efficiency. This technology has also enabled manufacturers to simulate and test new products and processes before investing in physical prototypes, reducing the time and cost associated with product development. As a result, digital twin technology has become a key driver of Industry[26].

After ranking digital twins as fifth of the top ten strategic technologies in 2017, Gartner estimated that by three to five years, billions of things would have digital twin designs[27]. It is worth mentioning that Gartner did not interpret this concept specifically in the field of production, and the scope of this concept expanded in facilities and environments as well as people, jobs, and processes. Digital twins were ranked number four out of the top ten key technology trends by Gartner two years later[25,28,29]. Digital twins focus on urban management also started to develop around 2018[30].

In general, the digital twin can be divided into three broad types at different stages of the product's life cycle, from the prototype stage to testing and optimization that show different timelines for use in the following process[25,31,32]:

- Digital twin prototype (DTP): It undertakes the work before the physical product is created.
- Digital twin instance (DTI): This digital twin is applied when a product is manufactured to conduct experiments in different scenarios.
- Digital twin aggregate (DTA): Collects information on the previous model (DTI) to determine a product's capabilities, execute prototypes, and test operating variables.

This width and diversity of digital twin models can provide professionals with a broad spectrum of applications, including logistics planning, product development and redesign, quality control/management, and systems planning[31,32].

According to **Figure 1**, the digital twin is a precise and detailed modeling of a virtual version of an entity or system in the real world, which should inherit the features of the original version as far as possible and have its life cycle[33]. This entity can be any physical reality, such as cars, buildings, places such as road networks, or even parts of cities. The essential feature of the digital twin is that it collects real-time data from various methods, such as data obtained from multiple sensors (IoT), and uses it to help decision-making with simulation, machine learning, and other technologies[34,35].

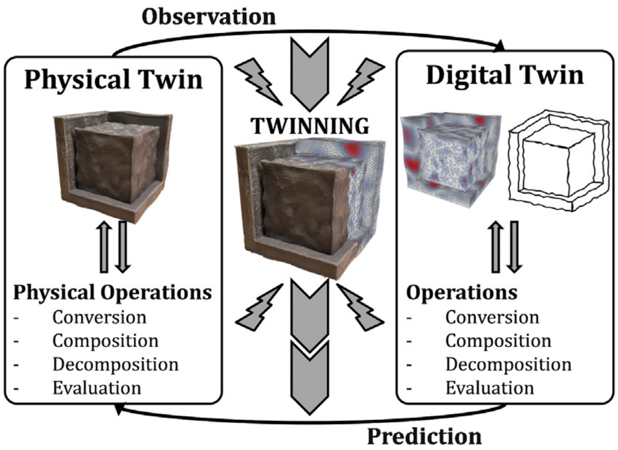

Figure 1. Various operations on physical and Digital Twins[33].

Figure 2 shows the essential elements of the city's smartness in a digital twin platform. The architecture consists of a services layer, virtual models, and physical entities connected in a digital platform. According to the figure, data, and services are connected to the services layer. In the layer of virtual models, the connection between data and virtual models is established. In the layer of physical entities of the real world, there is a connection between physical entities and data, all in the same digital platform[36].

According to this figure, by connecting virtual models and physical entities through data in the same digital platform, can help with better decision-making and management of the city's resources.

Therefore, using a digital twin can create mutual interaction between two physical and virtual counterparts at any moment. For instance, sensors and Internet of Things (IoT) technologies can provide information transfer, which updates the virtual model according to direct updates of the physical counterpart. The concept of DT presented by Professor Grieves consists of three parts[10,37]: the physical entity in real space, its digital copy in cyberspace, and the interaction between them. The digital maquette performs optimization and prediction for the physical entity, while the physical entity

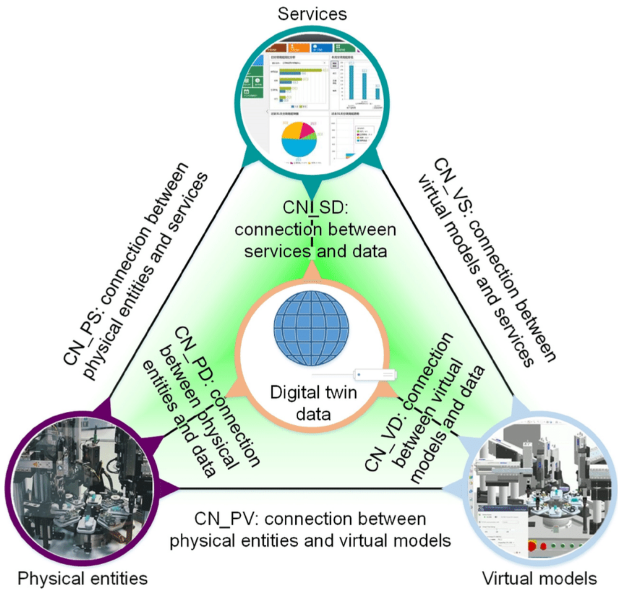

Figure 2. The concept of the basic elements necessary for making the city smart in a digital twin's context for different application domains[36].

reflects its behaviors and characteristics to the digital maquette to determine the system calibration components. In addition, the ability to update the virtual model based on real-time data from sensors and IoT technologies is a powerful tool for optimizing and predicting the behavior of the physical entity[35,38].

For all these technologies to be integrated and deployed in the digitalization process, one of the most basic requirements is to have a reliable, high-performance, and rapid network connection using advanced communication technologies (5G or 6G)[39]. A reliable and high-speed network connection is crucial for the successful integration and deployment of digitalization technologies such as the digital twin, artificial intelligence, and IoT. This network connection enables the transfer of data from physical systems to cloud hosts for analysis and deployment of AI algorithms. It also connects physical systems to their interfaces through web or mobile platforms, allowing real-time updates and remote control of devices. Therefore, it is important to invest in advanced communication technologies like 5G or 6G[24].

A conceptual model, as shown in **Figure 3**, represents the virtual city in the digital twin platform. This model includes various sensors distributed throughout the smart city, such as mobile phones and traffic cameras, which provide the location and visual information about street conditions. The data collected by these sensors are transmitted through the IoT platform to enable various smart city services. To synchronize the virtual city with the physical city, this data is then transferred to the virtual city server. This allows for real-time monitoring and analysis of the real environment[40].

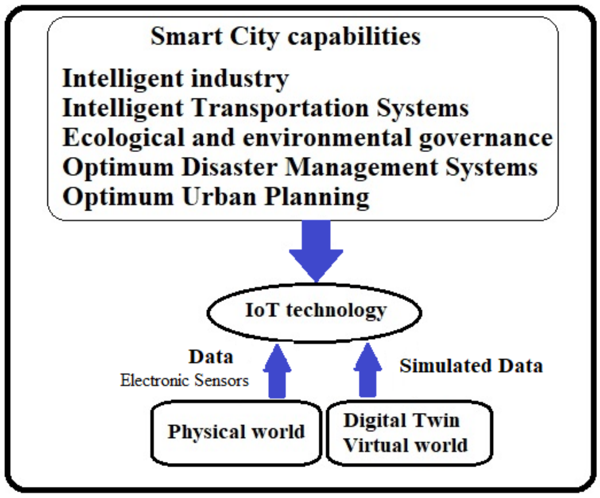

Figure 3. The diagram of the relationship between the digital twin's components and the smart city[33,36,40].

The fundamental concepts of this technology and its components, as well as the research policy, were established in this study by initially reviewing a variety of sources, then narrowing down to three reliable references in the fields of digital twin and smart cities (**Table 1**). Next, with a more detailed examination of more resources, various applied areas of these concepts that have been worked on in research articles were addressed.

3. Literatures review

Our literature review started with discovering related articles using academic search engines such as Google Scholar, ScienceDirect, SpringerLink, and Taylor & Francis. The main keywords include "digital twins", "smart city", "transportation system", and "traffic". The findings of the conducted research led to access to the various research articles in these areas and combinations form including all different search terms between the years 2016 and 2022. Evidently, some studies among a large number of findings were selected and examined in more depth. According to the previous studies, the growing number of published articles in the digital twins area is indicative of the science and technology world's fortunate towards this platform. The graphs of **Figure 4** illustrate that the number of articles published from 2017 to 2022 in various application domains is increasing significantly[49].

In another time range (1993 to 2022), according to **Table 2**, the researchers trained a model to evaluate the article topics on digital twins. The model was based on generating 20 key topics. First, the articles were assigned to the topic that was most heavily weighted in the article abstracts. For each topic, they selected the most popular words to describe the topic. The 20 topics are listed in descending order in **Table 2**[50].

According to the studies mentioned above, the digital twin has been used in various fields; the most significant of these fields are various industries where the advantages of digital twin are being used in the design and optimal management of systems. Since new technologies in optimal traffic management are dependent on things such as IoT and electronic sensors, the studying of digital twin technology in the field of industries is directly related to the field of traffic. So, in this study, we survey the technological findings of the digital twin in industrial fields, considering the strong connection between them and traffic issues in smart cities. Some important references are listed in **Table 3** with additional information about their year of publication, article type (journal or conference), and the number of citations. The increasing number of publications in this area also indicates that there is a growing interest in exploring the potential of digital twin technology to improve urban planning and design.

Research on the digital twin of the city is still in the primary steps. However, research on applying digital twin in smart cities, using its advantages such as optimal traffic management, has been done

Table 1. Definitions and basic concepts

Component	Smart city	DT	References No.
DT-Smart city-IoT	Smart cities benefit from accurate engineering tools, interactive communication, and city collective intelligence, improving operation efficiency and life quality.	Digital twin is gradually able to predict transitions in the systems and upcoming probable behavior by awareness of the infrastructure operation of the city, human dynamism, mutual dependence, cooperation capacity, and fluctuations in time and place.	[41–43]
DT-Smart city	The basis of the smart city establishment has evolved by combining the initial static 3D modeling level to the digital twins level with dynamic digital technology and static 3D model, which forms the new concept of the digitaltwins city.	Digital twin is a simulation process that fully uses physical models, sensors, operational historical data, etc., to merge multi-disciplinary information, as well as multi-physics, multi-scale, and multi-probability quantities.	[44–46]
Architecture and performance of digital twins in smart city	The digital twin of a smart city is a cyber component that reflects the physical urban system through real-time monitoring and synchronizing urban activities.	The rapid growth of urbanization puts more demands on cities restricted to operating with limited resources. Long-term solutions to overcome these restrictions lead to transforming cities into smart cities, which include implementing new technologies that mimic human intelligence.	[42,47,48]

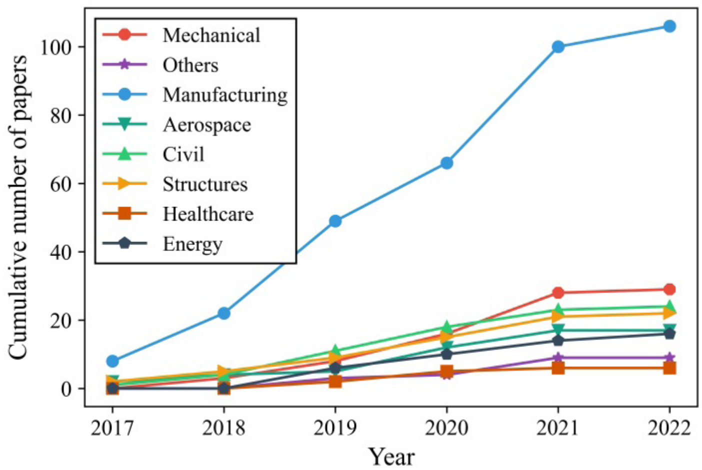

Figure 4. Cumulative number of papers in different application domains[49].

Table 2. Number of articles by topic (data taken from Scopus, records from January 1993 to September 2022)[50]

Topic name and number	Number of articles on topic
1-Robot_robots_robotic_human	283
2-Digital_twins_digital twins_twin	257
3-Construction_BIM_buiding_information	239
4-Power_grid_energy_power grid	175
5-Matching_cutting_tool_process	161
6-Patients_healthcare_health_medicine	149
7-Ship_vessel_ships_marine	139
8-Fatigue_crack_damage_structural	133
9-Teaching_students_education_learning	120
10-Ontology_knowledge_semantic_ontologies	107
11-Logistics_supply_supply chain_chain	106
12-Maintenace_predictive maintenance_prediction	90
13-City_urban_cities_smart	87
14-Systems_MBSE_engineering_systems engineering	87
15-Blockchain_sharing_data_decentralized	84
16-Security_attack_cyber_attacks	80
17-Bridge_structural_bridges_monitoring	79
18-Fault_diagnosis_fault diagnosis_faults	78
19-Battery_batteries_lithium-ion_charging	70
20-Driving_vehicle_vehicles_traffic	61

Table 3. Some research sources related to the field of digital matching, smart city, and traffic management

Row	References No.	Main theme	Journal or conference	DTs in IoT, transportations, and traffic	DTs in 3D information modelling and GIS	DTs in industry and production	Citation	Date of publication
1	[32]	Product life cycle, big data, cyber and physical convergence	Journal			✓	1,727	2018
2	[9]	Online digital twin design of logistics systems with simulation logic of a single (modularized) model	Conference			✓	17	2018
3	[10]	Surveying the concepts of digital twins, its obstacles and opportunities, and the relationship between digital twins and system engineering	Journal			✓	508	2017
4	[25]	Comprehensive and in-depth review of the literature to analyze digital twin from the perspective of concepts, technologies, and industrial applications	Journal			✓	423	2021
5	[26]	Optimizing the industrial production line using digital twin	Journal			✓	26	2021
6	[36]	Examining the 5D digital twin model	Journal			✓	254	2021
7	[37]	Providing an up-to-date picture of the main DT components, their features, and interaction problems	Journal			✓	171	2021
8	[8]	Focusing on the construction of DTs; determining (methodologically) how to design, create and connect physical objects with their virtual counterpart	Journal		✓	✓	11	2022
9	[49]	Digital twin concepts and the use of uncertainty quantification and optimization methods in digital twin technology	Journal		✓	✓	3	2022
10	[38]	The use of digital twins in increasing energy efficiency and sustainability	Journal			✓	25	2020
11	[51]	The concept of evolutionary digital twin (EDT); A more accurate approximation of the physical world through supervised learning	Journal			✓	19	2021
12	[52]	Evaluating basic digital twin concepts in the field of smart production with the help of basic enabling technologies such as data-based systems, machine learning and artificial intelligence, and deep learning	Journal			✓	13	2021
13	[53]	Development of simulation models based on intelligent objects in logistics activities	Journal			✓	28	2021
14	[54]	Designing a method for modeling human-machine cooperation based on digital twin using VQA (visual question answering)	Journal			✓	21	2021

Table 3. (*Continued*)

Row	References No.	Main theme	Journal or conference	DTs in IoT, transportations, and traffic	DTs in 3D information modelling and GIS	DTs in industry and production	Citation	Date of publication
15	[55]	The possibility of analyzing systems in real-world conditions using digital twin models	Journal			✓	20	2019
16	[35]	The use of digital twin in optimal building management, its advantages and disadvantages	Journal		✓	✓	132	2019
17	[14]	Integrated application of GIS and BIM in smart city concepts	Journal		✓	✓	134	2017
18	[56]	Using BIM building information modeling and combining it with GIS in digital twin and smart city	Journal		✓	✓	2	2022
19	[57]	Examining the dimensions of underpass roads using online map data in digital twin	Journal	✓	✓		1	2022
20	[58]	Redesign and reengineering of production processes using the Internet of Things and simulation methods in the realization of the digital twin model	Journal	✓			9	2021
21	[59]	Development of digital twin workflow for building the environment of a bridge	Journal	✓	✓		6	2022
22	[60]	Investigating a general functional framework for digital twin in simulating a physical object in the context of a software	Journal	✓			209	2020
23	[61]	Synchronization of transportation infrastructure by connecting real-time data from the physical system to a virtual GIS environment	Conference	✓	✓		9	2020
24	[62]	Application of digital twin in transportation systems; Examining the concepts of digital shadow, digital model and digital mirror	Journal	✓		✓	8	2021
25	[63]	Using digital twin to facilitate the design and deployment of Internet of Vehicles-based systems	Journal	✓		✓	79	2022
26	[50]	Developing a proper methodology for visualizing the digital-twin science landscape using modern bibliometric tools, text-mining, and topic-modeling, based on machine learning models	Journal		✓	✓	new	2022
27	[64]	Improving the traditional management systems of AGV vehicles (Automated Guided Vehicles) using digital twin capabilities	Conference	✓		✓	80	2022
28	[65]	Solving urban traffic problems using digital twin	Journal	✓			37	2021
29	[66]	Providing urban road planning approach based on digital twin (DT), MCDM, and GIS called DT-MCDM-GIS framework	Journal	✓	✓		12	2022
30	[17]	Intelligent development of transportation infrastructure with a focus on smart cities and digital twin	Journal	✓		✓	9	2022
31	[67]	Designing a system for predicting and preventing accidents using digital twin and artificial intelligence	Journal	✓			1	2022
32	[68]	Manufacturing, Industry 4.0 and DTS	Journal			✓	1,097	2015
33	[69]	Investigating the challenges of implementing digital twin applications for logistics systems	Journal	✓		✓	42	2019
34	[63]	Real-time mapping mechanism, construction of the digital twin-based machining process evaluation, process evaluation driven by digital twin data	Journal		✓	✓	86	2019
35	[71]	Integrating physical and numerical models of structural materials at several length scales in an advanced digital twin of artifact systems	Journal			✓	26	2019
36	[72]	Using machine learning model, IoT fog or edge data analytics, data lake for traffic and vehicle data on public cloud environments, and 5G communication to leverage virtual models for vehicles	Journal	✓			72	2018
37	[73]	Considering specific domains within intelligent transportation in which DT technology is applied in combination with the Internet of Things and 5G technologies	Conference	✓	✓	✓	1	2022

Table 3. (*Continued*)

Row	References No.	Main theme	Journal or conference	DTs in IoT, transportations, and traffic	DTs in 3D information modelling and GIS	DTs in industry and production	Citation	Date of publication
38	[74]	Simulation of urban mobility by developing a digital replica of a roadway network with signalized intersections in an urban setting where vehicle and traffic signals of real-time data	Journal	✓			9	2109
39	[75]	Providing a working solution for SPaT/MAP (Signal Phase and Timing and MAP as intersection geometry) standard-based communication, specifically for automotive proving ground usage to have a flexible traffic control system	Journal	✓			2	2023
40	[76]	Microscopic motorway simulation with real-time data integration during system run-time to propose a novel paradigm in motorway traffic modeling	Journal	✓			new	2023
41	[23]	Developing a mobility digital twin (MDT) framework, which is defined as an artificial intelligence (AI)-based data-driven cloud–edge–device framework for mobility services consisting of three building blocks in the physical space (namely, human, vehicle, and traffic)	Journal	✓		✓	31	2022
42	[6]	Conducting a systematic review to identify the development of the emerging technologies facilitating the evolution of BIM to digital twins in built environment applications	Journal	✓	✓		127	2021
43	[43]	Data analyzing BD in the smart city, IoT, and safe data processing by using the multi-source data collected in the smart city, deep learning algorithm, forwarding the distributed parallelism strategy of convolutional neural network	Journal	✓	✓	✓	109	2022
44	[77]	Summarizing the different disciplinary classifications of GIS and BIM functional integration, distilling the value of data, and discussing the ontology-based data integration approach with combination of GIS and BIM on integration applications in smart cities	Journal	✓	✓		31	2022
45	[78]	Analyzing the overview of GIS technology exploring the digital twin technology, and discussing the modeling process of the road traffic digital twin system	Journal	✓	✓		11	2021

in recent years. This review article aims to identify the potentials, challenges, and needs of using DT technology to smarten the urban traffic management systems and consequently increase the efficiency, sustainability, and quality of life in cities. For this purpose, the review helps the research programs' development and evaluation of the progress of each specific topic. We investigate the digital twin technology in three related scopes to the pivot of this research: Digital twins in industries and engineering, digital twins and geographic information modelling, and ultimately, IoT and digital twins in transportation and traffic control. The three selected review parts highlight the importance of considering geographic information modeling and IoT in conjunction with digital twin technology to create a more comprehensive and effective solution for urban traffic management. By bringing together these different technologies, cities can create more efficient traffic systems that improve the quality of life for residents while also promoting sustainability. Overall, the article provides valuable insights into the potential of digital twin technology to revolutionize urban traffic management and create smarter, more sustainable cities.

The statistical distribution of the materials examined in this research in the three mentioned areas is shown according to the statistical chart in **Figure 5**. According to this diagram, digital twin research and its application in the field of traffic is expanding, and of course, it is one of the basic needs of developing modern urban planning. **Figure 5** also shows that there is a lot of potential in the field of traffic control, although less attention has been paid to it than in the field of industries.

3.1 Digital twin in industries and engineering

Hofmann *et al*. presented the implementation of digital twin based on the Internet of Things and cloud technology to support decision-making using real-time data in the operations of port areas. Using operating forecasts based on the process simulation in this research, they deployed digital twin technology to assist truck dispatching operators. In this research, the simulation process was developed using Python SimPy, and the cloud services are subsequently called by the sensors connected to the Internet of Things after the events in the physical system. This architecture enables the integration and organization of port operations and leads to the optimal management of port infrastructures[69].

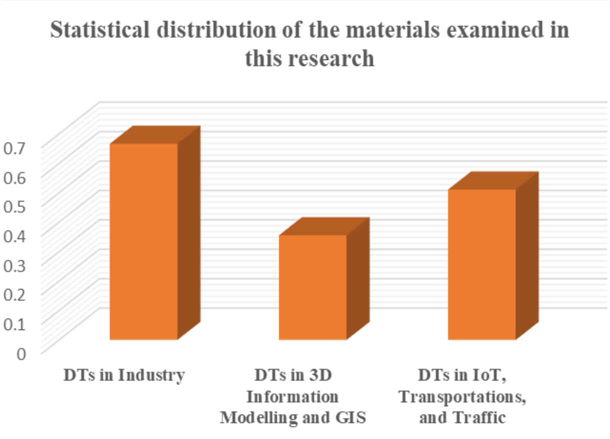

Figure 5. Statistical distribution of the materials examined in the research in 3 areas.

Minerva *et al*. have described the digital twin as the simulation of a physical object in a software platform. They acknowledge that the software object, called a logical object, reflects all the essential properties and characteristics of the original object in a specific application context. In their study, DT related IoT application scenarios and the preparation of a framework for evaluating the possibility of its implementation in modern software architectures have been discussed. In addition, the DT concepts have been mainly emphasized with middleware architectures for implementing with the Internet of Things. They concluded that the eventual possibility for the widespread use of the DT idea will most likely be the industrial internet or industry 4.0 scenarios[60].

Coelho *et al*. presented the architecture of digital twin for internal logistics management. They implemented a simulation-based decision support tool for internal logistics systems. The digital twin is employed by the decision support system in this research as a tool that handles an operation, such as the generation and dissemination of information, or is used interchangeably in other contexts due to its modularity. By adding the decision support system dimension, the researchers have expanded the five-dimensional digital twin (with the physical entity, virtual space, service system, data integration, and communication between them) to a six-dimensional digital twin[53].

Wang *et al*. addressed the technology of Visual Questions Answering (VQA) using digital twin to increase the efficiency of systems. The study proposed a method for modelling human and machine cooperation based on digital twin. Utilizing VQA technology in digital twin as a tool for modelling the human and machine interaction system for structured integration allows for the realization of intricate settings for human and machine cooperation[54].

Lin *et al*. introduced the concept of the Evolutionary Digital Twin (EDT) and the development of intelligent industrial products. The researchers in this research developed the EDT as a product of a more accurate approximate model of the physical world by applying supervised learning. According to this study, machine learning-based (supervised and reinforcement) parallel simulation in several cyberspaces may be used to jointly seek for industrial production policy optimization. Eventually, the authors concluded that relying on EDT's new concept can eliminate the lack of flexibility and compatibility in developing the industrial product. With new suggested technology, the accurate virtual product can create behavioural policies with higher operation[51].

Warke *et al*. addressed the evolutions in equipment scope, processes, or existing devices with sensors and other Cyber-Physical Systems (CPS). They introduced a digital twin framework as a combination of technologies that enable users to monitor, simulate, control, optimize, and identify defects and trends continuously, reducing the likelihood of human-prone errors. They allude to the use of vital technologies such as data-driven systems (data-driven system), machine learning, artificial intelligence, and deep learning to create digital twin for monitoring, simulation, control, and optimization in industrial processes[52].

Lu *et al*. referring to the urgent need the practical methods for re-engineering production and effective production process for small and medium enterprises (SMEs), address the accurate evaluations of the production line performance and traditional methods of value stream mapping (VSM) for performing the tasks of reengineering the production process. In this research, they proposed a digital twin VSM approach to organize small and medium-sized SMEs organizations by integrating the Internet of Things (IoT) and the Efficiency Validate Analysis (EVA) simulation framework. Using this method, the production of SMEs in redesigning and reengineering of production processes is easily facilitated[58].

By referring to the widespread use prediction of digital twins (DTs) in two-thirds of the world's largest industrial companies; in the future decade, Pregnolato *et al*. addressed the increasing need to create DTs in architecture, engineering, and construction (AEC) process with the improvement of the procedures, and proper joint procedures along with use cases. They proposed a step-by-step workflow process to develop a DT for a real-world physical entity based on Clifton Suspension Bridge data in Bristol (UK). In this paper, the authors developed a five-step workflow process for constructing DTs in the built environment, which is aligned with Gemini's three principles (targeting and usefulness of DT, maintaining the security and quality in DT, ownership and specific rules in DT) (Gemini Principles). The five-step processes included: data and requirements acquisition (1), digital modeling (2), dynamic data transfer (3), data/model integration (4), and operations (5). All actions and workflow were applied on the Clifton Suspension Bridge (Bristol, England), and its digital twin was designed and built[59].

Alexandru *et al*. improved the Automated Guided Vehicles (AGV) traditional management systems by using digital twins capabilities. While pointing out that AGVs are mainly unmanned vehicles that exist in a fully controlled environment, the researchers acknowledged that some features of traditional fleet management software could be removed or replaced with new ones. The authors have introduced a link between the simulated space and the real world as a solution for the evolution of fleet management systems in the form of digital twins and using the input of intelligent sensors[64].

3.2 Digital twin and geographic information modelling

Ambra *et al*. used new simulation technologies and real-time data in transportation models. Relying on increasing computing power thanks to the Internet of Things (IoT) technologies and GIS platforms, they were able to implement dynamic decision-making processes in transportation systems and get real-time flexibility. Using GIS, they provided real-time simulation with accurate and realistic routing for moving agents. The agents were used to depict vehicles' characteristics, movements, and functionality. They used Digital Elevation Model (DEM) as a central model in the 3D simulation of the environment and simultaneously investigated the concept of the digital twin and its potential role in transportation[61].

Dou *et al*. used GIS and BIM fusion modeling as the data carrier platform and the original technical support for the future urban operation centers, the digital twin of cities, and smart cities. Based on the analysis of the features and advantages of GIS and BIM Fusion, they proposed a method of constructing a spatiotemporal data visualization platform for GIS and BIM fusion. This research has described and analyzed the overall architecture of the platform, multi-dimensional and multi-spatial scale visualization, spatial analysis for GIS and BIM integration, etc. The developed system provides a practical solution for building a visual spatiotemporal platform[22].

Jiang *et al*. investigated urban road planning, based on a combination of digital twin, multi-criteria decision making (MCDM), and GIS, called DT-MCDM-GIS framework. They provided the research with an integrated environment for analysis by combining and simultaneously applying the DT to digitize the physical world and providing different data for the whole process alongside using the GIS. In addition, by using MCDM solutions, with the possibility of defining the related criteria, they were able to create a suitable approach for urban road planning that is functional, economical, people-friendly, and environmentally friendly. Finally, considering the construction of new roads and the widening of the old roads to reduce traffic congestion, they succeeded in providing an alternative route for drivers according to their habits[66].

Xia *et al*. studied the integration of GIS and BIM and related the details of creating digital twin technology with the production of City Information Modelling (CIM), which includes modeling, monitoring, analysis, simulation, and 3D visualization of smart cities. They introduced the Internet of Things (IoTs) technology, derived from cloud computing, big data, and communication technologies, as a pioneering tool and method for realizing CIM. On the other hand, researchers believe that the hardware costs required to process BIM data of a city are beyond imagination. The consequence of this matter makes it impossible to address the various problems on a regional or city scale only using the BIM platform. Hence, besides the BIM technology through applying GIS, which has facilities such as robust spatial databases and computing capabilities for the effective management of multi-source data and provides better use of geospatial information in urban areas, and handling big data management at the city level, unnecessary hardware requirements can be significantly reduced[56].

3.3 IoT and digital twins dedicated to transportation and traffic control

Several causes of traffic congestion and ways to open traffic in emergencies for emergency vehicles are discussed in Chandana *et al*. They proposed a network of sensors and load cells model that estimates the number of vehicles on a specific road based on electrical signals. As a result, the approximate amount of time is estimated when the traffic light should turn green to open the traffic on that road. This research aims to propose a traffic management system based on the Internet of Things, which includes many RFID and sensors that transmit the data wirelessly. By prioritizing the traffic of emergency vehicles, it provides an intelligent solution to possible congestion problems by emphasizing the priority of emergency vehicles[79].

Kumar *et al*. proposed a real-time and cognitive and advanced, extensible, and AI-inspired solution to precisely and perfectly measure the traffic congestion situation. In this research, they have used many data such as real-time road and vehicle data through fog or edge data analytics, driver history, behavior, and intention data through machine learning (ML) and deep learning (DL), data lake at the cloud for stocking historical information, Intelligent Transport System (ITS), the virtual vehicle (VV) model—digital twin, and blockchain as a service for vehicles. Accordingly, they could come out with a real-time and cognitive traffic congestion avoidance solution[72].

Masum *et al*. proposed a real-time Traffic Management System (TMS) using the Internet of Things (IoT) and data analysis. In this research, they used ultrasonic sensors to measure traffic density. After analyzing the sensor data, they adjusted the time system controller of the traffic signal with the traffic management algorithm and sent data to a cloud server through a Wi-Fi module. Eventually, the proposed system could predict the possible traffic congestion at an intersection point[80].

Rudskoy *et al*. discussed using digital twins and artificial intelligence in intelligent transportation systems to solve transportation networks' main problems and their practical development. Based on artificial intelligence algorithms, the researchers analyzed the previous information, including the sensors installed in the road transport network, and stored in the information system. In addition, integrating these services with prediction analysis and digital twin of the road network would provide visualization about the problematic areas of the city and facilitate the planning for the transportation network development. The result of the research fully fulfills the three main functions of the intelligent transportation system, including organizing efficient traffic flow, optimizing traffic dispersion, emergency service management in case of accidents, providing information about road conditions to all interested ones, and developing the transportation infrastructure[65].

Sarrab *et al*. addressed intelligent traffic monitoring using emerging technologies such as the Internet of Things (IoT) and artificial intelligence (AI). In this research, an IoT-based system model was designated to collect, process, and store real-time traffic data, which is processed through microcontrollers with Wi-Fi. The acquired information is sent to an IoT platform for further action. The goal of the study was to enhance vehicle mobility by providing real-time traffic information during traffic jams and unexpected traffic situations via the roadside messaging unit[81].

Ali *et al*. reviewed the research works on digital twin (DT) technology for intelligent transportation systems, focusing on the use of DT in electro-mobility and autonomous vehicles. They surveyed specific domains within intelligent transportation in which DT technology is applied in combination with the Internet of Things and 5G technologies and electric vehicle services, such as tracking, monitoring, battery management systems, and connectivity, and how they can be addressed effectively through DT[73].

Dasgupta *et al*. surveyed a DT approach for adaptive traffic signal control to improve user driving experience. They developed DTs to simulate vehicles close to the intersection and vehicles' waiting time at the immediate upstream intersection. They used a microscopic traffic simulation, a simulation of urban mobility, by developing a digital replica of a roadway network with signalized intersections in an urban setting where vehicle and traffic signal data were collected in real-time. Their proposed model can balance waiting time across a signalized network to improve the travel driving experience in congested areas, and it can be scalable on the city-wide network[73].

Kosaka *et al*. addressed the application of digital twins in domestic transportation systems. They examined the major trends in this research scope and the identification of future research directions. In addition, they introduced concepts such as digital shadow, digital model, digital mirror, material handling, material flow, and internal logistics in developing digital twin for internal transportation systems. The method used in this research refers to the creation of solutions obtained from optimization, prediction, or machine learning techniques. In this system, real-time data is obtained from real and physical objects and mutually receives the necessary decision-making parameters calculated in a DT[62].

Guo *et al*. investigated Internet of Vehicles (IoV) usage in digital twins. They have introduced the Internet of Vehicles (IoV) as the integration of Ad-hoc vehicular networks (VANETs) and the Internet of Things (IoT), which is considered a collection consisting of various devices in vehicles, such as embedded processors and internal units, with intelligent connectivity. Significant usage of IoV is providing real-time traffic information to users and decision-makers. Given the technical challenges in designing and implementing IoV-based systems, which exist in part due to the social, functional, and complexity requirements associated with increasing scale, range of devices, and connected systems, DTs are recommended to facilitate the design, testing, and implementation of such systems[63].

Lv *et al*. created a TA (traffic accidents) prevention and prediction system based on DTs and artificial intelligence (AI) to prevent TA and ensure the safety of life and property of drivers and pedestrians. The authors designed and implemented the TA and optimized it with a two-scale decomposition equation and artificial fish swarm (AFS). In the initial step of the process, the two-scale decomposition equation is combined with the long short-term memory (LSTM) network to construct a new LSTM network. Second, the original TA time series data (TSD) is decomposed with a two-scale decomposition equation into several sub-layers to reduce its instability and provide more stable data in the sub-layers for the deep learning (DL) prediction process. Second, the original TA time series data (TSD) is decomposed with the two-scale decomposition equation in the beneath layers' part to reduce its instability and provide more stable data in the sub-layers for the deep learning (DL) prediction process. Finally, the results of predicting losses caused by TA in different periods indicate the prediction performance of the proposed hybrid model significantly compared to real models[67].

In another study, Jiang *et al*. addressed the original road widening using DT technology. The researchers acknowledged that many existing roads could not meet the modern traffic needs of modern society because they were designed according to past traffic conditions; therefore, they considered road widening, one of the most effective methods to improve the service level. They first built the BIM of the widened road based on the digital twin of the original route. Then, according to the BIM model of the road widened and the digital twin of the underpass, they could examine the distances and redesign the underpass. An obvious result of the research is creating an economical method for redesigning the existing underpass in the original road widening project and using online map data without field surveys[57].

Wu *et al*. addressed the current state of the intelligent development of transportation infrastructure with a tendency toward smart cities. They analyzed that the technology of DTs and artificial intelligence have significant advantages in classifying transportation infrastructure and the management of the transportation's geospatial information. The realization of transportation infrastructure digitizing requires the integration of several data sources, the combination of BIM, GIS, and aerial photography data of traffic for creating a digital transportation infrastructure platform with a large storage capacity. Eventually, these technologies, with the effective combination of AI and DTs, become the basis for the maximum value of data[17].

Katzorke *et al*. proposed to utilize digital proving ground twins in order to verify the reliability of driving simulations by test replication under real environmental conditions and they have claimed the track geometries, environmental conditions, such as adverse weather, were identified as the most important aspect of a digital proving ground twin. For the optimization of traffic flows, a whole road network could be digitalized to constitute a digital twin. In this research, they describe a digital proving ground twin based on dynamic processes such as weather or traffic and they study a prioritization of elements of a proving ground based on the six-layer model that should be digitalized. They concluded that portraying only the road's geometry and permanent infrastructure, such as road markings, is not sufficient for the vehicle development domain[82].

During the literature review, no empirical article was identified that precisely discusses or recommends the required attributes of a digital twin proving traffic control system. Therefore, the lack of empirical research on the required attributes of a digital twin for traffic control systems highlights the need for further exploration in this area. This explorative study aims at covering the gap of knowledge and can facilitate further research toward traffic-controlling digitalization. By doing so, this research can facilitate further research and development in the field of traffic control testing digitalization, ultimately leading to more efficient and effective traffic management. The results of this study can also contribute to the acceleration of the implementation of digital twin technology.

4. Categorization of digital twin applications in intelligent traffic management

One of the smart city strategies is recognized for its contribution to raising the economic and environmental sustainability of communities while also enhancing the services offered to their citizens. A city's efficiency and livability are significantly influenced by its traffic. Due to unwelcome traffic, monotonous motor vehicles, accidents brought on by traffic, and inadequate transportation, millions of hours of people's time are lost every day on various metropolitan routes as a result of the trend toward urbanization[74]. In addition to wasting time, traffic harms urban environments, produces various forms of pollution, and overall decreases the quality of life for its inhabitants. By leveraging technology in this way, cities can reduce the need for physical travel and improve the efficiency of their transportation systems. For example, a digital platform that provides real-time updates on traffic conditions and suggests alternative routes can help drivers avoid congestion and reduce travel time[78,81]. Meanwhile, creating an electronic government can play an essential role in reducing unnecessary trips and thus reducing urban traffic. An electronic city is one where the majority of activities are made feasible by electronic and Internet-based infrastructure. Developed countries and smart cities are currently using the benefits of the Internet of Things to reduce traffic congestion in ITSs. ITS uses a range of technologies including IoT, computer vision, and artificial intelligence to collect and analyze data from various sources such as traffic sensors, cameras, and GPS devices to control traffic-heavy in crowded and traffic-heavy cities. This data is then used to make real-time decisions that optimize traffic flow, reduce congestion, and improve safety[83].

So far, considerable research has been done on traffic management systems. The various traffic statistics across cities and roads networks show that the number of road accidents is on the rise, the traffic congestion is becoming alarming, the car population is growing fast, the time being spent on the roads is increasing, and the fuel and time wastage due to traffic snarl is definitely higher. The researchers and authorities are trying to solve these annoying problems through some activities like growing the number of traffic signals steadily to regulate the escalating traffic by growing a family of traffic management systems that automate several aspects. However, intelligent traffic monitoring is still an active and innovative research topic due to emerging technologies such as the IoT and AI. Implementing intelligent traffic monitoring systems as helpful assistants, that utilize IoT and AI technologies can help to improve traffic management and reduce congestion. Digital twin technology can be particularly useful in this context, as it allows for the creation of virtual models of traffic networks that can be used to simulate and optimize traffic flow. Using this technology can help to reduce congestion, improve safety, and minimize fuel consumption and emissions. Additionally, digital twins can be used to monitor and analyze real-time traffic data, allowing for more effective decision-making and response to changing traffic conditions. The traffic management authorities by this technology will be able to make more informed decisions about traffic flow and implement more effective strategies to reduce congestion, such as adjusting traffic signals in real-time[16,76,84].

Overall, the Internet of Things has a wide range of applications in traffic management and has the potential to greatly improve safety, efficiency and it has so far been applied to smart city traffic management in a number of useful ways, including:

(1) Internet of Things and smartening traffic light control systems: Intelligent traffic light (ITS) or intelligent transportation system is dependent on different technologies that determine the timing of green and red lights at each intersection according to the volume of traffic in each section.

(2) Activating the intelligent park system through the Internet of Things: In intelligent parking lots based on the Internet of Things, magnetic sensors or similar hardware are installed inside the parking lot and send the parking lot condition to the parking management platform. The end user then uses the preferred application or the web-based system to view the vacant parking spaces before entering the parking lot and reserves the nearest appropriate space for a certain day and time.

(3) Intelligent emergency assistance in traffic accidents through the Internet of Things with rescue vehicles: This category of systems works on the basis of the Internet of Things in road accidents to monitor traffic flow and detect accidents or incidents in real-time, allowing for quicker response times by emergency services and provides service with the possibility of routing, infrastructure protection, and traffic management.

(4) Cameras and sensors in cars counting and estimating traffic volumes: These are able to measure and classify vehicles, detect the presence or passage of vehicles, determine the time and space distance between cars, figure out the current and average volume of traffic, and provide various statistics and reports. The traffic counter system uses artificial intelligence and image processing and is used in road networks. These technological tools can also gather data on traffic patterns and optimize transportation routes to reduce congestion and improve overall efficiency and to enforce traffic laws and improve safety on the roads.

These control systems have been equipped to many various traffic lights for very prominent and pervasive in urban areas for enabling smooth flow of pedestrians as well as vehicle drivers. There are also high-fidelity video cameras in plenty along the roads, expressways, tunnels, etc., to activate and accelerate a variety of real-time tasks for pedestrians, traffic police, and vehicle drivers. As cities become more populated and traffic becomes more congested, there is a need for more advanced and sophisticated solutions to manage traffic flow. The fast-growing traffic conundrum insists on highly sophisticated and technology-intensive solutions for the transport world. According to studies, conventional IT-enabled ITSs are found insufficient and obsolete in the increasingly connected and complicated transport world. According to the aforementioned, it is clear that the use of the Internet of Things has shown promise in improving traffic management in cities, but there is still much research and development needed to fully optimize its potential. Therefore, the management of lengthy commutes is still a subject that needs to be studied and investigated in greater detail in order to address any current shortcomings in light of issues facing large cities and the expanding needs of citizens[72,83,85,86].

Additionally, as cities continue to grow and evolve, the needs and demands of citizens will also change, requiring ongoing innovation and adaptation in traffic management strategies. Therefore, it is important to continue studying and investigating the use of the Internet of Things in traffic management to ensure that it remains effective and relevant in addressing the challenges faced by modern issues.

Fortunately, the technology domain is also on the fast track to producing breakthrough technologies and tools for simplifying and streamlining the process toward producing highly competitive and cognitive transport systems and services. Using famous technologies enormously contributes to the faster realization of next-generation transport solutions[73].

If a development activity is aiming at improving an object detection function for an automated vehicle, a singular vehicle or the driving system itself could be digitally modeled and regarded as a simulated twin. On the infrastructure side, for instance, a whole proving ground or an individual traffic light controller could be digitalized as a twin[73,84]. Some of the technologies that are contributing to the faster realization of next-generation intelligent transport solutions include:

(1) Artificial intelligence (AI): AI is being used to develop intelligent transportation systems that can analyze traffic patterns, optimize routes, and improve safety on the roads.

(2) Big data analytics: The vast amount of data generated by transportation systems can be analyzed to identify trends and patterns, enabling better decision-making and more efficient transportation systems.

(3) Internet of Things (IoT): IoT sensors and devices can be used with the advancement of big data (BD), IoT, artificial intelligence (AI), geographic information systems, and global positioning, as a new generation of information technology. The linkage of all these technologies in the DT technology is a critical element of the digital wave trends. Besides, improving city visualization as a primary goal of 3D modeling of city information takes the lead in transportation applications in planning, maintenance, security, and other aspects[73]. Innovative facilities for reproducing the actual world in an observable virtual realm, as well as the potential for intelligent traffic management and testing solutions, are made possible by the employment of advanced technologies such as DT together with IoT and big data. Owing to achieving a more accurate depiction, it helps improve comprehension of the urban environment and lessen design mistakes. By creating virtual replicas of real-world environments and testing different scenarios, designers can identify potential problems and make improvements before construction begins[87].

The strength of the DT lies in collecting the big data, visualizing it, and conducting statistics in which advanced analysis tools are used to improve the sector and help in decision-making[70,71]. This technology can build up traffic simulation and adds real-time and closed-loop characteristics as well as analysis and optimization functions (e.g., object detection and path planning) that interact with other objects within the simulation. Real-time monitoring and analysis of traffic data can help to identify areas where accidents are more likely to occur, and predictive analytics can be used to anticipate potential hazards before they happen. Hence, one of the most substantial efforts using digital twins is, to reduce the number and severity of road accidents[76,88].

5. System architecture

The digital twin as a digital model can have many different applications in the most effective administration of urban affairs by connecting to a physical system and maintaining continuous data connection procedures wi h a high level of synchronization in the network[24]. The system architecture for a digital twin typically involves three main components: the physical system, the digital model, and the communication infrastructure network that connects them. The physical system refers to the real-world object or system that the digital twin is modeling. This could be anything from a piece of industrial equipment to an entire city's infrastructure. The digital model is a virtual representation of the physical system. It is created using data collected from sensors and other sources and is typically built using advanced modeling and simulation tools.

A set of requirements, such as minimum delay in synchronization and real-time communication, and maintaining the data security and quality in the system, must be met by the network infrastructure to ensure that the service operates reliably[84]. As a result, the network is in charge of providing the digital twin with real-time data that represents the state of the physical system. At the same time, it transfers control data from the digital twin to its physical counterpart[24].

In general, the main components in the architecture of digital twin systems for traffic controling, according to **Figure (6)** include:

(1) Data collection and processing: The system should be able to collect and process data from technological tools (consisting of sensors and applications connecting sensors) to create a digital representation of the physical system or the real-world (consisting of complications and information of the physical world).

(2) Model creation: The system should be able to create a mathematical model of the physical system based on the collected data (consisting of portrayal and simulation processes of the 3D software output such as CAD and information modeling such as BIM).

(3) Simulation: The system should be able to simulate the behavior of the physical system based on the mathematical model.

(4) Visualization: The system should be able to visualize the digital twin in a way that is easily understandable and can provide insights into the behavior of the physical system to visualize the digital easily to understand and interact. This can include 2D or 3D visualizations, dashboards, graphs, and other interfaces.

(5) Analytics, prediction, and decision-making about traffic: The system should be able to perform analytics on the digital twin data to identify patterns, trends, and anomalies (using artificial intelligence and decision support techniques). This can include machine learning algorithms, statistical analysis, and other techniques to analyze the data collected from the physical system and provide insights into its behavior.

(6) Communication and integration layer consisting of applications: The system should be able to communicate and integrate with the physical system and provide feedback to optimize its performance such as control systems or maintenance (final output such as the smart city, intelligent traffic system, etc.). The application layer is designed as a means of organizing the platform's capabilities.

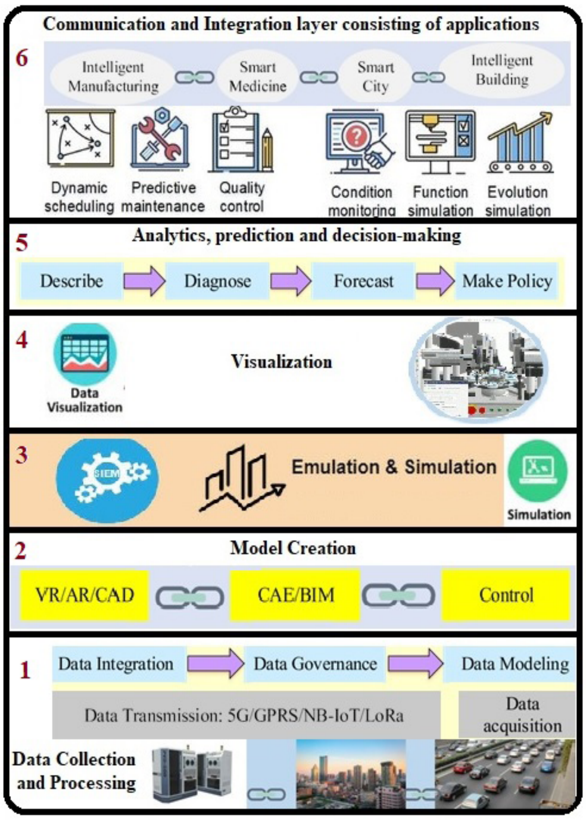

Figure 6. The proposed digital twin architecture in transportation applications[44,67,89,90].

Layering helps different connectors and functions better meet and support the needs of applications[89,90]. In the traffic-controlling field, by using layering in intelligent transportation systems, digital twins can help identify potential traffic problems in the common application layer, and then provide solutions and policies in the industry application layer to address these problems. Answering the question "What traffic problem could happen?" inside the common application layer through diagnosis, forecasting, and policy making, particularly from DT, entails identifying potential future traffic problems. The received responses are shown in the industry application layer and may be utilized for traffic administration and control[35,44,84]. This technique can help improve traffic management and control, and ultimately enhance overall mobility and safety on the roads.

6. Discussions and conclusions

Smart cities are designed to leverage technology and data to improve the quality of life for citizens, enhance sustainability, and increase economic opportunities. By integrating different systems and services, smart cities can optimize resource use, improve transportation, reduce crime, and enhance public services from controlling the city's physical development to a broad concept consisting of physical, social, and knowledge infrastructure. Intelligent transportation systems (ITS) are a critical component of smart cities, and the application of digital technologies (DTs) in this area can have a significant impact on transportation efficiency, safety, and sustainability. By definition, digital twin provides a virtual representation of a physical system (and related environment and processes) that is updated through the exchange of information between the physical world and virtual systems. Most DT research focuses on the conceptual development of DT frameworks for implementing digital twin in a specific scope. Accordingly, this paper summarized the potential technologies for implementing DT and information modeling for traffic control, considering the different components in the DT model. Smart cities under the umbrella of digital twins can also help cities achieve economic, environmental, and social sustainability. Virtual models can help make decisions planned and provide solutions to the complex challenges that modern cities are ahead. For instance, real-time responses to traffic problems can evolve with real-time information from digital twins of the status of traffic lights, the amount of traffic, and the safety and usability of the roads to enable the assessment of rapid and secure transportation. The usage of IoT in the context of traffic and transportation-enhancing devices, as previously said, has a considerable influence on resolving the traffic issues in densely populated cities and partially lowering the air pollution brought on by these issues. For this purpose, many modeling methods and techniques currently used in digital twins in the area of the smart city were reviewed and analyzed. We also categorized studies based on their application and focus on industries and manufacturing, information modeling, and transportation and traffic.

In optimization problems such as best routing, the goal is to move the system along a desired path, that is, to move it along a desired trajectory of states to escape heavy traffic. One of the most widely used advantages of urban traffic management is the routing of low-traffic roads for drivers, the possibility of announcing road accidents and identifying optimal routes for timely assistance in this area. In order to optimize the motorway performance, it is important to have a good understanding of the traffic flow patterns, as well as the capacity and limitations of the motorway infrastructure. This can be achieved through data analysis and modeling techniques. Additionally, it is important to consider the impact of external factors such as weather conditions and events on the traffic flow, such as accidents. According to this study, one of the important approaches to solving the traffic problem is to focus on location intelligence and transform large amounts of data linked to the location of traffic nodes. ITS technologies such as real-time traffic monitoring and control systems, dynamic message signs, and adaptive traffic signal control can be used to improve traffic flow and reduce congestion on the motorway.

Digital twin technology and ITSs together can be particularly useful in optimizing motorway performance by providing a virtual representation of the motorway system. In general, using the DT ground model and parallel DT instance, we can anticipate problems. A DT that follows location intelligence and shows various transportation information in the form of geospatial layers can lead to decision-making maps of transportation infrastructure quality. In a traffic node area, the average traffic volume, asphalt quality, road width, and previous traffic accidents can be recorded and presented as geospatial layers in the GIS component of a DT. Based on this, more advanced spatial analysis are also possible.

If we identify problems early enough, we have enough options (control strategies) to mitigate them and, thus, optimize the motorway performance. This virtual model can be used to simulate different scenarios such as accidents or heavy traffic and test various control strategies in a safe and controlled environment before they are implemented in the real world. By identifying potential problems and optimizing the system's performance, they can achieve the best course of action based on objective criteria such as best routing. In this way, the best action among many can be selected based on certain objective criteria (e.g., what speed limits are appropriate for the next few minutes on the main sections of the motorway to increase throughput or which path can be selected to escape from the heavy-traffic) and safely deployed in the real motorway environment. Thus, the objective is to slow down and harmonize the incoming traffic in the congestion zone in order to relieve the congested sections of the motorway and restore the traffic flow to a steady state if possible.

This makes digital twins a valuable tool for smart cities as they can provide a virtual representation of the city's physical infrastructure and enable city planners and decision-makers to simulate and test different scenarios before implementing them in the real world.

One of the biggest challenges of using digital twins in optimal traffic management and timely assistance during accidents is the issue of suitable sensors for traffic estimation and synchronization time and communication between the two systems. Minimizing the time limits of synchronizing the digital twins with their physical counterparts is one of the most critical challenges of this technology in traffic control. Because the passage of time is critical in addressing issues with traffic and providing assistance in cases of traffic accidents, every second might be crucial. The accuracy and timeliness of the data collected by sensors are crucial for the effectiveness of digital twin technology in traffic management. The synchronization time between the physical system and the digital twin can be a critical factor in ensuring timely response to traffic issues and accidents. Therefore, it is important to use reliable and efficient sensors and communication systems to minimize synchronization time and ensure accurate data collection. The use of precious spatio-temporal analysis can further enhance the effectiveness of traffic management strategies. By recording and presenting transportation information in this way, it is possible to gain a more comprehensive understanding of traffic node areas and identify opportunities for improvement.

Therefore, any study and achievement that can overcome this limitation and any progress in sensors and artificial intelligence that can reduce the time of connection and data exchange between these two environments, will further realize the exploitation of DTs in traffic control. Another question that arises is whether digital equivalent can be combined with VGI in traffic control and routing. Combining digital twin technology with VGI (Volunteered Geographic Information)[90,91] in traffic control and routing can potentially lead to more accurate and real-time information. Currently, existing applications such as Google and Waze use citizens' participation and real-time information for navigation. Combining it with traffic control sensors, it can be a new field in vehicle routing and navigation.

A vital advantage of the digital twin is that it provides insight into future patterns and plans. In the same way, for the digital counterpart of the city in intelligent transportation systems, such benefits can be listed as follows:

(1) Real-time monitoring, control, and data collection: Through real-time digital twin, updates exchange between the physical and digital systems of the road network and vehicles. It is possible to monitor all updates, acquire all the data needed to manage traffic volumes, and during incidents, this ability provides optimal routing of emergency vehicles and the possibility of controlling the road network if necessary.

(2) Enhanced safety: By monitoring real-time data from vehicles and the road network, digital twins can identify potential hazards and alert drivers and authorities in real-time. This can help prevent accidents and improve overall safety on the roads.

(3) Reduced environmental impact: The result of accurate modeling and receiving real time information leads to a reduction in traffic and air pollution.

(4) Continuity of activity and processes through remote access: These generations of digital twins, can be accessed by remote users worldwide. Ensure the inclusion and cooperation of all parties involved in times of disruption despite not being physically present in the physical system. This architecture can also be developed for traffic control.

(5) Increased efficiency: Facilitating testing of different scenarios and cases before implementation. In the physical systems of the road network, digital twins provide a platform for testing already routed paths and applying the best ones to increase the effectiveness of this approach during a real crisis.

(6) Improved decision-making: Digital twins can provide decision-makers with real-time data and insights to make informed decisions. This can help authorities respond quickly and effectively to incidents and emergencies, and optimize traffic flow during peak hours. The GIS component can be very effective in this respect.

(7) Cost savings: Digital twins can help reduce costs by optimizing traffic flow, reducing congestion, and improving safety. This can lead to lower maintenance costs, reduced fuel consumption, and fewer accidents.

(8) Highly informed decision support: Through the collected real-time data of the vehicle's GPS and regional traffic data on one platform and having easy access to spatio-temporal analysis tools enables rapid decision-making, and timely assistance, with better and more efficient information.

(9) Predictive maintenance and optimal timing: The integration of artificial intelligence and machine learning can develop techniques in digital twin forecasting processes to evaluate optimal system maintenance times to avoid disruption. Artificial intelligence techniques can also optimize scheduling processes to increase productivity.

(10) Advanced risk assessment: A digital twin allows virtual testing of various traffic management solutions to perform the what-if analysis to evaluate the testing of these solutions without influencing the physical system.

DT technology can help authorities make informed decisions about implementing new traffic management strategies and assessing potential risks before they occur. Overall, this technology can revolutionize the transportation industry by providing real-time data, improving traffic flow, enhancing safety, reducing environmental impact, facilitating decision-making, optimizing maintenance, and enabling advanced risk assessment.

The benefits of using 3D modeling in the development of smart cities include improved urban planning and design, better visualization of complex urban systems, and more effective communication among stakeholders. The challenges may include the cost of implementing and maintaining 3D modeling systems, the need for accurate and up-to-date data, and the potential for privacy concerns related to the collection and use of data.

In general conclusion, because the technology of the digital twin is still in its infancy, additional research efforts to test and apply digital twins will promote growth and technological maturity, making it an essential pillar in the era of digital transformation. However, some limitations hinder the growth and development of DT, which include:

(1) Most DT models include only 3D geometric models. Although some recent research has considered physical models, the dimensions of behavioral modeling and rule modeling in these environments still need to improve.

(2) Data transmission occurs with delay and change because the current methods of data transmission between two real and virtual environments suffer from an accuracy drop and transmission speed due to the high volume of simultaneous data transmission; and

(3) Therefore, current algorithms and analysis methods still need improvement in precision and speed.

(4) One of the key challenges in implementing digital twins in traffic control is the shortage of data. While there is a significant amount of data generated by traffic sensors, cameras, and other sources, this data is often fragmented and difficult to integrate into a single, comprehensive model. Additionally, there may be gaps in the data, particularly in areas with limited sensor coverage or where data collection is not a priority. Without a complete and accurate representation of the traffic system, it can be challenging to develop effective strategies for management.

(5) Lack of standardization: The lack of standardization in data collection and processing can also hinder the implementation of digital twin technology in traffic control. Different cities and regions may use different types of sensors and data collection methods, making it difficult to create a standardized model that can be applied across different locations.

(6) Technical expertise: Implementing digital twin technology requires specialized technical expertise, particularly in areas such as data analytics, simulation, and modeling. There may be a shortage of professionals with knowledge related to this technology.

To overcome these limitations, governments and researchers should collaborate in many aspects:

(1) Collaboration between different stakeholders, such as traffic controllers, city planners, and technology experts, can help to identify the key challenges and opportunities in traffic control. Additionally, the collaboration between industry, academia, and government can help to accelerate the development and adoption of DT technology, leading to more efficient and effective operations in various industries.

(2) Investment in technology: Governments and technical organizations can invest in digital twin technology to develop accurate and reliable simulations of traffic conditions. This can be done through partnerships with technology companies or by creating in-house teams to develop the technology.

Furthermore, in some technical obstacles, researchers and developers should focus on improving the accuracy and speed of data transmission, developing more advanced algorithms and analysis methods, and expanding the scope of DT models to include more than just 3D geometric models.

Conflict of interest

The authors declare no conflict of interest.

References

1. Li YW, Cao K. Establishment and application of intelligent city building information model based on BP neural network model. Computer Communications 2020; 153: 382–389. doi: 10.1016/j.comcom.2020.02.013.
2. Kim TH, Ramos C, Mohammed S. Smart city and IoT. Future Generation Computer Systems 2017; 76: 159–162. doi: 10.1016/j.future.2017.03.034.
3. Visan M, Negrea SL, Mone F. Towards intelligent public transport systems in Smart Cities; Collaborative decisions to be made. Procedia Computer Science 2022; 199: 1221–1228. doi: 10.1016/j.procs.2022.01.155.
4. Yencken D. Creative cities. In: Sykes H (editor). Space, place and culture. Australia: Future Leaders; 2013.
5. Nour El-Din M, Pereira PF, Poças Martins J, Ramos NM. Digital twins for construction assets using BIM standard specifications. Buildings 2022; 12(12): 2155. doi: 10.3390/buildings12122155.
6. Deng M, Menassa CC, Kamat VR. From BIM to digital twins: A systematic review of the evolution of intelligent building representations in the AEC-FM industry. Journal of Information Technology in Construction 2021; 26: 58–83. doi: 10.36680/j.itcon.2021.005.
7. Lu Q, Parlikad AK, Woodall P, *et al*. Developing a digital twin at building and city levels: Case study of West Cambridge campus. Journal of Management in Engineering 2020; 36(3): 05020004. doi: 10.1061/(ASCE)ME.1943-5479.0000763.
8. Segovia M, Garcia-Alfaro J. Design, modeling and implementation of digital twins. Sensors 2022; 22(14): 5396. doi: 10.3390/s22145396.
9. Korth B, Schwede C, Zajac M. Simulation-ready digital twin for realtime management of logistics systems. In: 2018 IEEE International Conference on Big Data (Big Data); 2018 Dec 10–13; Seattle. New York: IEEE; 2019. p. 4194–4201.
10. Grieves M, Vickers J. Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. In: Transdisciplinary perspectives on complex systems. Cham: Springer; 2017. p. 85–113.
11. Lafioune N, St-Jacques M. Towards the creation of a searchable 3D smart city model. Innovation & Management Review 2020; 17(3): 285–305. doi: 10.1108/INMR-03-2019-0033.
12. Yang C, Mao L. Analysis on risk factors of BIM application in construction project operation and maintenance phase. Journal of Service Science and Management 2021; 14(2): 213–277. doi: 10.4236/jssm.2021.142013.
13. Jovanović D, Milovanov S, Ruskovski I, *et al*. Building virtual 3D city model for smart cities applications: A case study on campus area of the University of Novi Sad. ISPRS International Journal of Geo-Information 2020; 9(8): 476. doi: 10.3390/ijgi9080476.
14. Ma Z, Ren Y. Integrated application of BIM and GIS: An overview. Procedia Engineering 2017; 196: 1072–1079. doi: 10.1016/j.proeng.2017.08.064.
15. Muthuramalingam S, Bharathi A, Gayathri N, *et al*. IoT based intelligent transportation system (IoT-ITS) for global perspective: A case study. In: Internet of Things and big data analytics for smart generation. Cham: Springer; 2019. p. 279–300.
16. Elsagheer Mohamed SA, AlShalfan KA. Intelligent traffic management system based on the Internet of Vehicles (IoV). Journal of Advanced Transportation 2021; 2021: 4037533. doi: 10.1155/2021/4037533.
17. Wu J, Wang X, Dang Y, Lv Z. Digital twins and artificial intelligence in transportation infrastructure: Classification, application, and future research directions. Computers and Electrical Engineering 2022; 101: 107983. doi: 10.1016/j.compeleceng.2022.107983.
18. Kumar DM, Arthi R, Aravindhan C, *et al*. Traffic congestion control synchronizing and rerouting using LoRa. Microprocessors and Microsystems 2021; 104048. doi: 10.1016/j.micpro.2021.104048.
19. Vaidya RB, Kulkarni S, Didore V. Intelligent transportation system using IOT: A review. International Journal for Research Trends and Innovation 2021; 6(9): 80–87.
20. Wang J, Hou L, Chong HY, *et al*. A cooperative system of GIS and BIM for traffic planning: A high-rise building case study. In: Luo Y (editor). Cooperative design, visualization, and engineering. In: The 11th International Conference on Cooperative Design, Visualization and Engineering; 2014 Sept 14–17; Seattle. Berlin: Springer; 2014. p. 143–150. doi: 10.1007/978-3-319-10831-5_20.
21. Schrotter G, Hürzeler C. The digital twin of the city of Zurich for urban planning. PFG–Journal of Photogrammetry, Remote Sensing and Geoinformation Science 2020; 88(1): 99–112. doi: 10.1007/s41064-

020-00092-2.
22. Dou S, Zhang H, Zhao Y, *et al*. Research on construction of spatio-temporal data visualization platform for GIS and BIM fusion. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences 2020; XLII-3-W10: 555–563. doi: 10.5194/isprs-archives-XLII-3-W10-555-2020.
23. Wang Z, Gupta R, Han K, *et al*. Mobility digital twin: Concept, architecture, case study, and future challenges. IEEE Internet of Things Journal 2022; 9(18): 17452–17467. doi: 10.1109/JIOT.2022.3156028.
24. Mashaly M. Connecting the twins: A review on digital twin technology & its networking requirements. Procedia Computer Science 2021; 184: 299–305. doi: 10.1016/j.procs.2021.03.039.
25. Liu M, Fang S, Dong H, Xu C. Review of digital twin about concepts, technologies, and industrial applications. Journal of Manufacturing Systems 2021; 58(Part B): 346–361. doi: 10.1016/j.jmsy.2020.06.017.
26. Erol T, Mendi AF, Doğan D. Digital transformation revolution with digital twin technology. In: 2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT); 2020 Oct 22–24; Istanbul. New York: IEEE; 2020. p. 1–7.
27. Panetta K. Gartner's top 10 strategic technology trends for 2017 [Internet]. Stamford: Gartner; 2016 [updated 2016 Oct 18]. Available from: https://www.gartner.com/smarterwithgartner/gartners-top-10-technology-trends-2017.
28. Panetta K. Gartner's top 10 strategic technology trends for 2018 [Internet]. Stamford: Gartner; 2017 [updated 2017 Oct 3]. Available from: https://www.gartner. com/smarterwithgartner/gartners-top-10-technology-trends-2018.
29. Panetta K. Gartner's top 10 strategic technology trends for 2019 [Internet]. Stamford: Gartner; 2018 [updated 2018 Oct 15]. Available from: https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2019.
30. Ferré-Bigorra J, Casals M, Gangolells M. The adoption of urban digital twins. Cities 2022; 131: 103905. doi: 10.1016/j.cities.2022.103905.
31. Del Giudice M, Osello A (editors). Handbook of research on developing smart cities based on digital twins. Hershey: IGI Global; 2021.
32. Tao F, Cheng J, Qi Q, *et al*. Digital twin-driven product design, manufacturing and service with big data. The International Journal of Advanced Manufacturing Technology 2018; 94: 3563–3576. doi: 10.1007/s00170-017-0233-1.
33. Schleich B, Anwer N, Mathieu L, Wartzack S. Shaping the digital twin for design and production engineering. CIRP Annals 2017; 66(1): 141–144. doi: 10.1016/j.cirp.2017.04.040.
34. Guo H, Chen M, Mohamed K, *et al*. A digital twin-based flexible cellular manufacturing for optimization of air conditioner line. Journal of Manufacturing Systems 2021; 58(Part B): 65–78. doi: 10.1016/j.jmsy.2020.07.012.
35. Khajavi SH, Motlagh NH, Jaribion A, *et al*. Digital twin: Vision, benefits, boundaries, and creation for buildings. IEEE Access 2019; 7: 147406–147419. doi: 10.1109/ACCESS.2019.2946515.
36. Qi Q, Tao F, Hu T, *et al*. Enabling technologies and tools for digital twin. Journal of Manufacturing Systems 2021; 58(Part B): 3–21. doi: 10.1016/j.jmsy.2019.10.001.
37. Semeraro C, Lezoche M, Panetto H, Dassisti M. Digital twin paradigm: A systematic literature review. Computers in Industry 2021; 130: 103469. doi: 10.1016/j.compind.2021.103469.
38. Park KT, Lee D, Noh SD. Operation procedures of a work-center-level digital twin for sustainable and smart manufacturing. International Journal of Precision Engineering and Manufacturing-Green Technology 2020; 7: 791–814. doi: 10.1007/s40684-020-00227-1.
39. Banafaa M, Shayea I, Din J, *et al*. 6G mobile communication technology: Requirements, targets, applications, challenges, advantages, and opportunities. Alexandria Engineering Journal 2023; 64: 245–274. doi: 10.1016/j.aej.2022.08.017.
40. Hu W, Zhang T, Deng X, *et al*. Digital twin: A state-of-the-art review of its enabling technologies, applications and challenges. Journal of Intelligent Manufacturing and Special Equipment 2021; 2(1): 1–34. doi: 10.1108/JIMSE-12-2020-010.
41. Mohammadi N, Taylor J. Knowledge discovery in smart city digital twins. In: Proceedings of the 53rd Hawaii International Conference on System Sciences; 2020 Jan 7–10; Maui. Honolulu: ScholarSpace; 2020.
42. Austin M, Delgoshaei P, Coelho M, Heidarinejad M. Architecting smart city digital twins: Combined semantic model and machine learning approach. Journal of Management in Engineering 2020; 36(4): 04020026. doi: 10.1061/(ASCE)ME.1943-5479.0000774.
43. Li X, Liu H, Wang W, *et al*. Big data analysis of the Internet of things in the digital twins of smart city based on deep learning. Future Generation Computer Systems 2022; 128: 167–177. doi: 10.1016/

j.future.2021.10.006.
44. Li D, Yu W, Shao Z. Smart city based on digital twins. Computational Urban Science 2021; 1: 1–11. doi: 10.1007/s43762-021-00005-y.
45. Taylor JE, Bennett G, Mohammadi N. Engineering smarter cities with smart city digital twins. Journal of Management in Engineering 2021; 37(6): 02021001. doi: 10.1061/(ASCE)ME.1943-5479.0000974.
46. Mylonas G, Kalogeras A, Kalogeras G, *et al*. Digital twins from smart manufacturing to smart cities: A survey. IEEE Access 2021; 9: 143222–143249. doi: 10.1109/ACCESS.2021.3120843.
47. Qian C, Liu X, Ripley C, *et al*. Digital twin—Cyber replica of physical things: Architecture, applications and future research directions. Future Internet 2022; 14(2): 64. doi: 10.3390/fi14020064.
48. Rafsanjani HN, Nabizadeh AH. Towards digital architecture, engineering, and construction (AEC) industry through virtual design and construction (VDC) and digital twin. Energy and Built Environment 2021; 4(2): 169–178. doi: 10.1016/j.enbenv.2021.10.004.
49. Thelen A, Zhang X, Fink O, *et al*. A comprehensive review of digital twin—Part 1: Modeling and twinning enabling technologies. Structural and Multidisciplinary Optimization 2022; 65(12): 1–55. doi: 10.1007/s00158-022-03425-4.
50. Kukushkin K, Ryabov Y, Borovkov A. Digital twins: A systematic literature review based on data analysis and topic modeling. Data 2022; 7(12): 173. doi: 10.3390/data7120173.
51. Lin T, Jia Z, Yang C, *et al*. Evolutionary digital twin: A new approach for intelligent industrial product development. Advanced Engineering Informatics 2021; 47: 101209. doi: 10.1016/j.aei.2020.101209.
52. Warke V, Kumar S, Bongale A, Kotecha K. Sustainable development of smart manufacturing driven by the digital twin framework: A statistical analysis. Sustainability 2021; 13(18): 10139. doi: 10.3390/su131810139.
53. Coelho F, Relvas S, Barbosa-Póvoa AP. Simulation-based decision support tool for in-house logistics: The basis for a digital twin. Computers & Industrial Engineering 2021; 153: 107094. doi: 10.1016/j.cie.2020.107094.
54. Wang T, Li J, Kong Z, *et al*. Digital twin improved via visual question answering for vision-language interactive mode in human-machine collaboration. Journal of Manufacturing Systems 2021; 58(Part B): 261–269. doi: 10.1016/j.jmsy.2020.07.011.
55. Haag S, Anderl R. Automated generation of as-manufactured geometric representations for digital twins using STEP. Procedia CIRP 2019; 84: 1082–1087. doi: 10.1016/j.procir.2019.04.305.
56. Xia H, Liu Z, Efremochkina M, *et al*. Study on city digital twin technologies for sustainable smart city design: A review and bibliometric analysis of geographic information system and building information modeling integration. Sustainable Cities and Society 2022; 84: 104009. doi: 10.1016/j.scs.2022.104009.
57. Jiang F, Ma L, Broyd T, *et al*. Underpass clearance checking in highway widening projects using digital twins. Automation in Construction 2022; 141: 104406. doi: 10.1016/j.autcon.2022.104406.
58. Lu Y, Liu Z, Min Q. A digital twin-enabled value stream mapping approach for production process reengineering in SMEs. International Journal of Computer Integrated Manufacturing 2021; 34(7–8): 764–782. doi: 10.1080/0951192X.2021.1872099.
59. Pregnolato M, Gunner S, Voyagaki E, *et al*. Towards civil engineering 4.0: Concept, workflow and application of digital twins for existing infrastructure. Automation in Construction 2022; 141: 104421. doi: 10.1016/j.autcon.2022.104421.
60. Minerva R, Lee GM, Crespi N. Digital twin in the IoT context: A survey on technical features, scenarios, and architectural models. Proceedings of the IEEE 2020; 108(10): 1785–1824. doi: 10.1109/JPROC.2020.2998530.
61. Ambra T, Macharis C. Agent-based digital twins (ABM-DT) in synchromodal transport and logistics: The fusion of virtual and pysical spaces. In: 2020 Winter Simulation Conference (WSC); 2020 Dec 14–18; Orlando. New York: IEEE; 2021. p. 159–169.
62. Kosacka-Olejnik M, Kostrzewski M, Marczewska M, *et al*. How digital twin concept supports internal transport systems?—Literature review. Energies 2021; 14(16): 4919. doi: 10.3390/en14164919.
63. Guo J, Bilal M, Qiu Y, *et al*. Survey on digital twins for Internet of vehicles: Fundamentals, challenges, and opportunities. Digital Communications and Networks 2022. doi: 10.1016/j.dcan.2022.05.023.
64. Alexandru M, Dragoș C, Bălă-Constantin Z. Digital twin for automated guided vehicles fleet management. Procedia Computer Science 2022; 199: 1363–1369. doi: 10.1016/j.procs.2022.01.172.
65. Rudskoy A, Ilin I, Prokhorov A. Digital twins in the intelligent transport systems. Transportation Research Procedia 2021; 54: 927–935. doi: 10.1016/j.trpro.2021.02.152.
66. Jiang F, Ma L, Broyd T, *et al*. Digital twin enabled sustainable urban road planning. Sustainable Cit-

ies and Society 2022; 78: 103645. doi: 10.1016/j.scs.2021.103645.

67. Lv Z, Guo J, Singh AK, Lv H. Digital twins based VR simulation for accident prevention of intelligent vehicle. IEEE Transactions on Vehicular Technology 2022; 71(4): 3414–3428. doi: 10.1109/TVT.2022.3152597.
68. Rosen R, Von Wichert G, Lo G, Bettenhausen KD. About the importance of autonomy and digital twins for the future of manufacturing. IFAC-PapersOnline 2015; 48(3): 567–572. doi: 10.1016/j.ifacol.2015.06.141.
69. Hofmann W, Branding F. Implementation of an IoT- and cloud-based digital twin for real-time decision support in port operations. IFAC-PapersOnLine 2019; 52(13): 2104–2109. doi: 10.1016/j.ifacol.2019.11.516.
70. Liu J, Zhou H, Liu X, *et al*. Dynamic evaluation method of machining process planning based on digital twin. IEEE Access 2019; 7: 19312–19323. doi: 10.1109/ACCESS.2019.2893309.
71. Okita T, Kawabata T, Murayama H, *et al*. A new concept of digital twin of artifact systems: Synthesizing monitoring/inspections, physical/numerical models, and social system models. Procedia CIRP 2019; 79: 667–672. doi: 10.1016/j.procir.2019.02.048.
72. Kumar SAP, Madhumathi R, Chelliah PR, *et al*. A novel digital twin-centric approach for driver intention prediction and traffic congestion avoidance. Journal of Reliable Intelligent Environments 2018; 4: 199–209. doi: 10.1007/s40860-018-0069-y.
73. Ali WA, Roccotelli M, Fanti MP. Digital twin in intelligent transportation systems: A review. In: 2022 8th International Conference on Control, Decision and Information Technologies (CoDIT); 2022 May 17–20; Istanbul. New York: IEEE; 2022. p. 576–581.
74. Dasgupta S, Rahman M, Lidbe AD, *et al*. A transportation digital-twin approach for adaptive traffic control systems. ArXiv 2021; abs/2109.10863. doi: 10.48550/arXiv.2109.10863.
75. Wágner T, Ormándi T, Tettamanti T, Varga I. SPaT/MAP V2X communication between traffic light and vehicles and a realization with digital twin. Computers and Electrical Engineering 2023; 106: 108560. doi: 10.1016/j.compeleceng.2022.108560.
76. Kušić K, Schumann R, Ivanjko E. A digital twin in transportation: Real-time synergy of traffic data streams and simulation for virtualizing motorway dynamics. Advanced Engineering Informatics 2023; 55: 101858. doi: 10.1016/j.aei.2022.101858.
77. Xia H, Liu Z, Efremochkina M, *et al*. Study on city digital twin technologies for sustainable smart city design: A review and bibliometric analysis of geographic information system and building information modeling integration. Sustainable Cities and Society 2022; 84: 104009. doi: 10.1016/j.scs.2022.104009.
78. Wang S, Zhang F, Qin T. Research on the construction of highway traffic digital twin system based on 3D GIS technology. Journal of Physics: Conference Series 2021; 1802(4): 042045. doi: 10.708/1742-6596/1802/4/042045.
79. Chandana KK, Sundaram SM, D'sa C, *et al*. A smart traffic management system for congestion control and warnings using Internet of things (IoT). Saudi Journal of Engineering and Technology 2017; 2(5): 192–196. doi:10.21276/sjeat.
80. Masum AKM, Chy MKA, Rahman I, *et al*. An Internet of things (IoT) based smart traffic management system: A context of Bangladesh. In: 2018 International Conference on Innovations in Science, Engineering and Technology (ICISET); 2018 Oct 27–28; Chittagong. New York: IEEE; 2019. p. 418–422.
81. Sarrab M, Pulparambil S, Awadalla M. Development of an IoT based real-time traffic monitoring system for city governance. Global Transitions 2020; 2: 230–245. doi: 10.1016/j.glt.2020.09.004.
82. Katzorke N, Vinçon C, Kolar P, Lasi H. Fields of interest and demands for a digital proving ground twin. Transportation Research Interdisciplinary Perspectives 2023; 18: 100782. doi: 10.1016/j.trip.2023.100782.
83. Vaidya RB, Kulkarni S, Didore V. Intelligent transportation system using IOT: A review. International Journal for Research Trends and Innovation 2021; 6(9): 80–87.
84. Bao L, Wang Q, Jiang Y. Review of digital twin for intelligent transportation system. In: 2021 International Conference on Information Control, Electrical Engineering and Rail Transit (ICEERT); 2021 Oct 30–Nov 1; Lanzhou. New York: IEEE; 2022. p. 309–315.
85. Abdellah AR, Mahmood OAK, Paramonov A, Koucheryavy A. IoT traffic prediction using multi-step ahead prediction with neural network. In: 2019 11th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT); 2019 Oct 28–30; Dublin. New York: IEEE; 2020. p. 1–4.
86. Burhan M, Rehman RA, Khan B, Kim BS. IoT elements, layered architectures and security issues: A comprehensive survey. Sensors 2018; 18(9): 2796. doi: 10.3390/s18092796.

87. Petrova-Antonova D, Ilieva S. Methodological framework for digital transition and performance assessment of smart cities. In: 2019 4th International Conference on Smart and Sustainable Technologies (SpliTech); 2019 Jun 18–21; Split. New York: IEEE; 2019. p. 1–6.
88. Demiyanushko IV. The virtual digital proving ground for carrying out tests of road arrangement elements at arrivals of vehicles. In: 2021 Intelligent Technologies and Electronic Devices in Vehicle and Road Transport Complex (TIRVED); 2021 Nov 11–12; Moscow. New York: IEEE; 2021. p. 1–6.
89. Al-Ali AR, Gupta R, Zaman Batool T, *et al*. Digital twin conceptual model within the context of internet of things. Future Internet 2020; 12(10): 163. doi: 10.3390/fi12100163.
90. White G, Zink A, Codecá L, Clarke S. A digital twin smart city for citizen feedback. Cities 2021; 110: 103064. doi: 10.1016/j.cities.2020.103064.
91. Vahidnia MH, Hosseinali F, Shafiei M. Crowdsource mapping of target buildings in hazard: The utilization of smartphone technologies and geographic services. Applied Geomatics 2020; 12: 3–14. doi: 10.1007/s12518-019-00280-9.
92. Vahidnia MH. Citizen participation through volunteered geographic information as equipment for a smart city to monitor urban decay. Environmental Monitoring and Assessment 2023; 195(1): 181. doi: 10.1007/s10661-022-10796-0.