The Role of Digital Twin Technologies in Resilient Cities

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Abstract

Cities are becoming increasingly vulnerable due to the growing impacts of climate change, natural disasters, and intense pressures on infrastructure systems. Traditional methods used to enhance urban resilience carry high costs, time requirements, and implementation challenges. This situation increases the need for digital and data-driven approaches that can analyze the complex dynamics of cities more effectively. The digital twin approach aims to create a digital reflection of the physical city, establishing interaction between virtual and real environments. It enables the modeling of risk scenarios, the development of disaster predictions, and the testing of intervention plans through simulations. This study explains the areas of application of digital twin technologies and their relationship with the concepts of smart cities and resilient cities. It also investigates the contribution of digital twin technologies to urban resilience using examples from around the world and Türkiye. The research method used is content analysis within a conceptual framework, and the comparison method is used in the analysis of resilient city characteristics, digital twin applications, and examples from different countries.

The first part of the research consists of conceptual definitions, while the second part includes case studies from around the world and Türkiye. The third part deepens the analysis of the concepts of smart cities and digital twins that contribute to the concept of urban resilience. The findings show that digital twin technologies in different countries contribute to urban resilience criteria. In conclusion, this study discusses the contributions that digital twin technologies can make to resilient city models.

Keywords: Digital Twin Technology, Urban Resilience, Disaster Management, Smart Cities, Data-Driven Planning.

JEL Codes: S56, Q55

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1. Introduction

Urban systems involve complex processes. Issues such as air pollution, inadequate infrastructure, traffic congestion, water issues and climate change threaten healthy living in cities. Environmental problems linked to climate change, in particular, create problems for urban infrastructure, making it imperative to accelerate solutions. Therefore, traditional approaches remain insufficient, and the transformation of cities into data-driven, flexible, and resilient systems is crucial for managing existing risks and preparing for future threats.

This study investigates data-driven digital twin technologies applicable in smart city systems. In recent years, advancements in IoT (Internet of Things) and location-based technologies have facilitated research on the creation of digital city replicas. Through digital twin technologies, a digital copy of cities can be created, and international applications demonstrate their effectiveness in disaster prevention and risk mitigation. This article presents various definitions of digital twin technologies in the literature, the developmental process of urban digital twin technologies, and examples of their applications. The research is grounded in the question: "How can digital twin technologies be leveraged in creating resilient cities?"

The study's methodology is based on content analysis of conceptual studies and examines the use of digital twin technologies in the context of the relationship between smart and resilient cities through a comparative analysis of applications in different countries. Following comparisons of the objectives, statuses, and contributions to urban resilience of digital twin projects developed in Türkiye and worldwide, planning and policy recommendations are presented, and the role of digital twin technologies in the context of resilient cities is discussed.

This review systematically searched the literature addressing the contribution of digital twin technologies to urban resilience. The review utilized Web of Science, Scopus, Google Scholar, ScienceDirect, and relevant national databases. In the literature search, English keywords such as "digital twin," "urban resilience," "smart city," and "disaster management" were combined using Boolean operators (AND, OR). The search included publications related to digital twin applications, urban resilience, disaster management, 3D city models, and smart city projects. The selected studies were examined in terms of country, risk type, application area, and contribution to urban resilience. In the conclusion, theoretical insights and comparative findings are evaluated in the context of their contributions to planning disciplines in the development of resilient cities.

2. Digital Twin Technology: Concept, Components, and Core Functioning

In general, digital technologies are important for processes that connect formal and rational knowledge with individuals' experiences to achieve smarter and more sustainable urban management, supporting intelligent and democratic planning processes (Dembski et al., 2020). Digital twins have the capacity to address complex challenges faced by cities (Dembski et al., 2020). In Japanese, the term conceptually refers to the collection of the states of objects or environments in the physical world, replicating and recreating them in digital space (Sorabatake, 2021). A digital twin is "a computerized model of a physical device that represents all functional characteristics and interacts with its operational components" (Chen, 2017). Batty (2018) highlights that the real value of digital twins lies in their capacity to simulate alternative scenarios rather than simply replicate existing conditions.

The concept was first introduced in the early 2000s by Michael Grieves (2014). The term focuses on representing a real object using digital tools, meaning a virtual copy of a physical product (Yang, 2022). NASA first introduced the concept of a "twin" in the Apollo Project in 2011, providing a detailed definition of digital twins: "Creating a virtual twin in a virtual network to predict and understand the existence of the real world" (Du, 2024). With advances in simulation and communication technologies, the digital twin concept was used in the aerospace sector by NASA and the U.S. Air Force in 2012 (Tao et al., 2019b: 5). Initially applied in industrial design and aerospace, digital twin technologies have since started to find new potential applications (White et al., 2021). Since its inception, however, the concept has expanded to characterize various digital simulation models operating alongside real-time processes of social, economic, and physical systems (Batty, 2018). It has been widely used in diverse fields such as manufacturing, aerospace, healthcare, and urban systems to optimize processes, reduce costs, and improve performance (Supianto et al., 2024).

Digital twin technologies refer to mapping real-world entities into the virtual space, synchronizing the virtual model with the real condition of the entities, and enabling interaction between virtual and real worlds (Tao et al., 2018). The digital twin concept consists of three components: physical data, virtual data, and data linking the real and virtual, collecting information such as physical models, real-time updates, and operational history, and reflecting entire life cycles by mapping entities into virtual models via multi-simulation technologies (Du, 2024). Digital twins produce city twins by enabling interaction

and operation of both real and virtual cities simultaneously through real-time visual dynamic monitoring and intelligent management of the real world via digital holographic simulation (Du, 2024). They allow the simulation of multiple options before physical action, enabling identification of strengths and weaknesses of each plan. This is particularly critical in situations where only one option can be selected among many competing plans with significant safety implications (White et al., 2021). Virtual simulations can be applied to guide decision-making in the real world (Wang, 2024). The idea of the digital twin has clearly emerged from the growing ability to link real-time data to models of urban processes (Batty, 2018).

The 2018 Tham Luang cave rescue operation in Thailand, where a youth football team and their coach were trapped, provides an example of the potential of digital twin technologies in disaster and rescue operations. This technology offers a significant advantage, particularly in high-risk decision-making scenarios where identifying a single correct solution is vital. In the Thai cave rescue operation, digital twin technologies were effectively utilized. Rescue teams created a digital copy of the cave, simulating its topography, water levels, air conditions, and potential rescue routes (Dixon, 2018). Consequently, various plans were tested in the virtual environment before conducting physically risky and time-consuming explorations. The digital twin model analysed water flow rates, oxygen levels, and the safety of evacuation paths, assisting diving teams in determining the least risky route (Puri, 2018).

Digital twin technologies are a technological concept that collects the states of objects and environments in the real world, replicates them in digital space, and reproduces them (Sorabatake, 2021) (Figure 1).
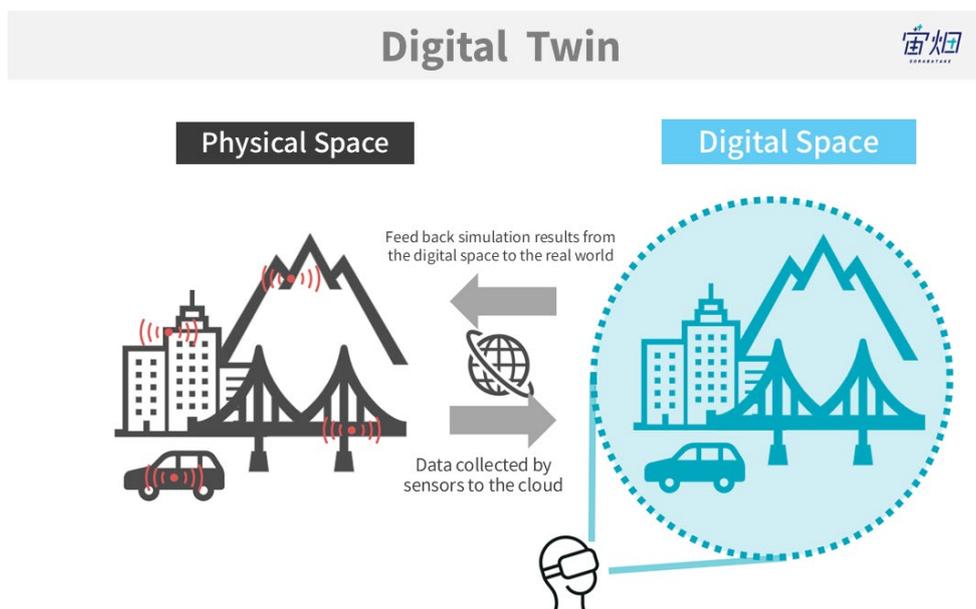

Figure 1. Schematic Representation of the Relationship Between Digital Space and Physical Space
Source: Sorabatake, 2021

A digital twin, through the alignment of virtual and physical worlds, enables the prevention of problems before they arise, the avoidance of downtime, and the planning of the future using simulations (Boschert & Rosen, 2016). With Industry 4.0, digital twins have become a fundamental component of cyber-physical systems (Alam & El Saddik, 2017). Through integration with technologies such as real-time data collection, IoT (Internet of Things), artificial intelligence, and big data analytics, digital twins have begun to be widely used both in production optimization and in predictive maintenance systems (Randanliev, 2022). According to data flow, the process can be divided into four stages: digitization of the physical domain, data collection, data analysis, and representation in the digital domain (Tao et al., 2019). In Formula 1 racing, digital twin technology creates virtual models of the vehicle and driver, simulating the impact of different driving strategies and vehicle settings on performance, thereby enabling the most efficient decisions during actual races.

Urban digital twins are an extended version of digital twins (Yang, 2022). "Most urban digital twin implementations focus on narrow application domains, and there is a clear lack of a generic framework to guide sustainable digital transformation across cities" (Supianto et al., 2024). Urban digital twin technology is based on Building Information Modelling (BIM) and is updated with real-time data (Du, 2024). Digital twin methodologies rely on comprehensive urban inventory datasets; moreover, the complexity of interactions in urban areas and disasters presents significant challenges in simulating disaster scenarios in densely populated regions (Wang et al., 2024).

Incorporating the digital twin concept inspired by these developments into disaster prevention research can provide quantitative guidance to enhance urban resilience by predicting or reproducing the impacts of disasters in a virtual environment (Wang et al., 2024). Digital twins allow pre-disaster planning, real-time emergency assessment, and post-disaster rescue insights (Wang et al., 2024).

In digital twin-based disaster resilience analysis for buildings and cities, three key issues should be addressed (Wang et al., 2024):

- How can building and city information be effectively obtained from the real world and mapped from reality to the virtual environment?
- How can disaster simulation models be established for buildings and cities in the virtual environment, ensuring accurate prediction or simulation of disaster processes?
- How can the simulation results obtained in the virtual environment be used to guide disaster prevention and mitigation strategies in the real world and establish a feedback loop from virtual to real?

Addressing these three issues allows the establishment of an effective digital twin cycle, providing a robust framework for rational disaster prevention and mitigation strategies (Wang et al., 2024).

Traditional methods for studying urban disaster resilience face high costs, ethical issues, and limited test sites, which digital twins help to overcome (Wang et al., 2024). Digital twins, which will be used in the production of planning and policy decisions in cities, can easily obtain data in cities with smart city infrastructure (White et al., 2021). Smart planning is important in increasing urban resilience, along with the increasing urban population and climate change issues (Almuhim, 2025). An urban digital twin can create a virtual copy of a smart city (Pang et al., 2021). In recent years, numerous urban studies have used digital twins in areas such as transport, infrastructure management, disaster management, urban planning, and health services (Pang et al., 2021).

An urban digital twin is a virtual representation of the built environment (Supianto et al., 2024). Supianto et al. (2024) consolidate definitions from various perspectives and propose the following definition: "An Urban Digital Twin is a dynamic and highly accurate representation of real-life assets of city systems and subsystems. This representation reflects their states and behaviours throughout the lifecycle and can be used safely to monitor, analyse, and simulate current and future conditions using data analytics, data integration, and artificial intelligence, aiming to improve citizens' quality of life and well-being."

The concept of digital twins originates from the representation of physical city assets. Geographic information systems, scaling to the building level, and the use of Building Information Modelling (BIM) software to address building performance in terms of energy, materials, and maintenance provide the context for comprehensive digital representations that can be scaled to all physical assets in the city. Clearly, such systems are a form of model because they represent the city digitally rather than materially, closely approximating the essential physical equivalents that compose the city (Batty, 2018).

3. Global and National Applications of Digital Twin Technology

Effective disaster management requires the simultaneous availability of multiple, diverse, and interconnected infrastructure datasets (Ford & Wolf, 2020). Digital twins are emerging as tools to forecast risks before disasters, prepare through simulations, take necessary precautions, enable rapid response during disasters, and support post-disaster recovery processes (Çubukçu et al., 2024). This section examines digital twin applications and use cases in different countries. The examples provided are intended to contribute to the study as examples of best practices developed in different countries. The projects examined at the country level were approached from the perspective of technological innovations that will increase urban resilience, reduce vulnerability, or accelerate post-disaster recovery.

3.1. Case Studies from Japan

Research indicates that Japan carries a high risk of natural disasters, prioritizing technology-based and smart applications for disaster management (Ölmez, 2025). In particular, the adoption of digital twin technology by local governments strengthens pre-disaster preparation, response, and recovery processes (Ölmez, 2025). Koshimura et al. (2025) state that the digital twin approach in Japan plays a significant role in pre-disaster risk analysis, early warning and simulation during disasters, and post-disaster damage assessment and recovery evaluations. The study proposes a dynamic, real-time digital twin technology with a feedback loop, integrating local government digital platforms, nationally developed tsunami simulation systems, and data from recent earthquakes (Koshimura et al., 2025). In this project, Koshimura et al. (2025) explain that it includes the dimensions of physical resilience, institutional resilience, and social resilience.

Project PLATEAU, conducted by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in Japan, aims to develop, utilize, and share 3D city

models as open data (MLIT, 2023). Approximately 250 cities' 3D digital models have been created under PLATEAU, including metadata such as building usage and construction year, and are used for purposes such as infrastructure analysis in city planning, optimization of transportation routes, and disaster scenario simulations (MLIT, 2023). PLATEAU is directly linked to the Society 5.0 vision, as it is one of the digital infrastructure projects supporting the integration of cyberspace and physical space (Uchiyama & Ishimaru, 2022).

Within the Society 5.0 framework, digital twin technologies are applied not only in infrastructure analysis but also in broad areas such as health, transportation, energy, and water management. This vision, combined with infrastructure projects like PLATEAU, supports Japan's evolution toward a "super smart society" (Japan Integrated Innovation Strategy, 2022).

One Concern is a technology company focused on disaster risk analytics; it offers digital twin solutions that enhance the resilience of infrastructure and communities (One Concern, 2022). Using data collected by the company in Japan, simulations can be conducted to determine which infrastructure

components fail first in disaster scenarios and how transport networks become inoperable (One Concern, 2022).

3.1.1. Real-time digital disaster system

The Real-Time Digital Disaster Twin System, developed in Japan, is a digital twin application designed to optimise preparedness and response processes for natural disasters. The system simulates the potential impacts on infrastructure and communities during major disasters such as tsunamis and earthquakes. Real-time data is collected from sensors, satellites and human movements; this data is used to model the spread of the disaster, flooding and infrastructure damage (Hokkaido University, 2023; Denkeishimbun, 2023). In this context, digital twin technology stands out as an important tool for assessing infrastructure resilience and planning the post-disaster recovery process (Hokkaido University, 2023). These data enable detailed comparisons between pre- and post-disaster situations by visualising the extent of damage, including coastal elevation and conditions in urban areas (Figure 2).
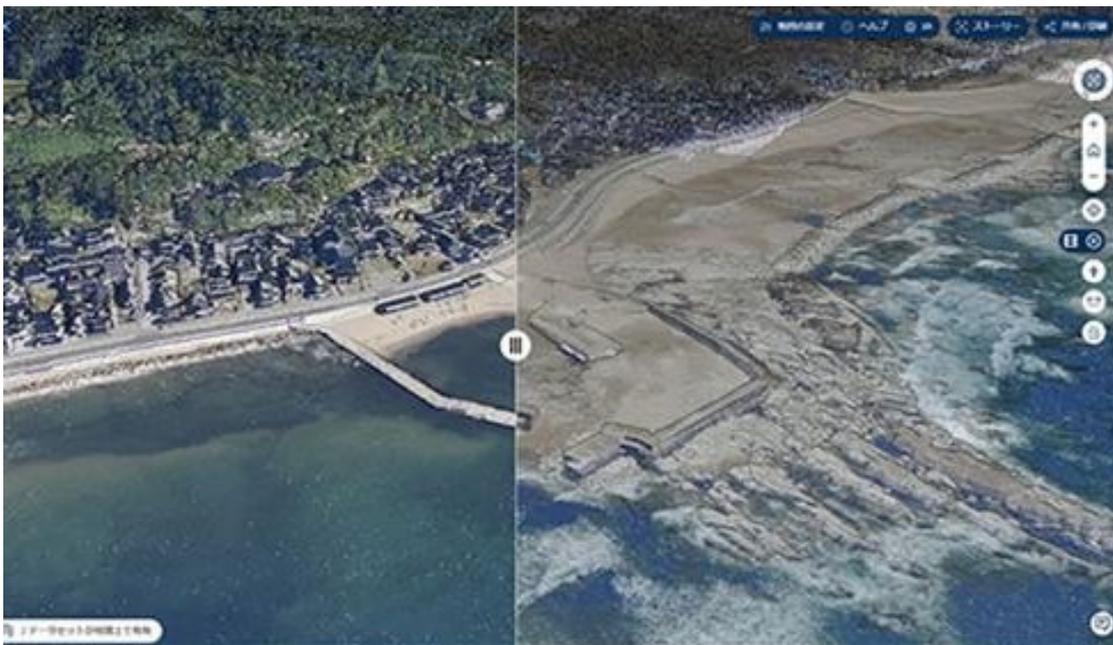

Figure 2. Before-and-After Comparison for Tokyo (Left: Pre-Disaster; Right: Post-Disaster)

3.1.2. Tokyo smart resilience platform

The Tokyo Smart Resilience Platform is a digital twin and smart city initiative led by the Tokyo Metropolitan Government. The platform aims to increase the city's resilience by integrating 3D digital models of the city, real-time river water levels, transport networks and other infrastructure data (Tokyo Metropolitan Government, 2024). The platform can simulate the performance of transport and energy infrastructure in disaster scenarios, thereby enabling the development of response plans. It also supports social dimensions, such as analysing transport accessibility and safety for women and vulnerable groups (Tokyo Metropolitan Government, 2024). The Tokyo Smart Resilience Platform provides a concrete example of the use of digital twin technology as a strategic tool in urban planning.

Examples in Japan demonstrate the applicability of digital twin technologies in terms of both infrastructure resilience and societal preparedness. While the Real-Time Digital Disaster Twin System supports

disaster management, the Tokyo Smart Resilience Platform enables city-scale data integration and resilience planning. This approach demonstrates that digital twin applications in Japan can be integrated at different scales and for different purposes, playing an important role in enhancing both urban and societal resilience.

3.2. Case Studies from Singapore

In 2014, Singapore launched the Smart Nation project to collect real-time data on land, buildings, transportation, water levels, and population movement. The government developed a 3D city model called Virtual Singapore. This model is used to plan infrastructure more effectively and to simulate how people and vehicles move through the city, helping reduce traffic congestion and improve construction processes (Sorabatake, 2021).

The Smart Nation initiative reflects Singapore's broader goals of improving digital services, involving citizens in decision-making, managing urban infrastructure, and strengthening social connections (smartnation.gov.sg). Within this framework, Virtual Singapore serves as a nationwide 3D platform that combines live data with spatial information. It demonstrates how digital twin technologies can be applied in dense urban settings by integrating detailed 3D models with real-time information. Its purpose is to support planning decisions, simulate flows (human/vehicle) to reduce congestion, and enhance construction/infrastructure project efficiency (smartnation.gov.sg). The Virtual Singapore platform, developed under the Smart Nation vision, integrates multi-layered data components at a national scale through 3D mapping (OECD/OPSI, 2024). Its application areas include "Urban Planning and Design," "Transportation Optimization," "Disaster and Risk Management," and "Industrial and Academic Uses" (OUP Academy).

H2i, in Singapore, develops digital models, simulation technologies, and big data analytics in the context of "water and urbanization," exemplifying applications of digital twin technologies in areas such as "water management," "climate risk," and "flood management" (h2i.sg). SITEM is a national-scale simulation model in Singapore that models the integration of transportation and energy infrastructures. Its features include integrating the large-scale traffic simulator "CityMoS" with the energy-grid optimization module "MESMO" (CityMoS, 2022). In this regard, SITEM functions as a decision support tool at the transportation-energy intersection (Figure 3).
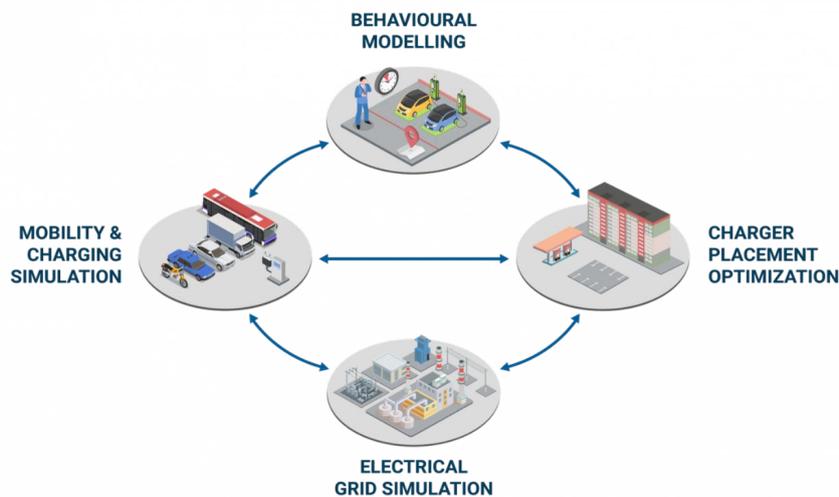

Figure 3. Digital Twin-Based Simulation Loop of Electric Vehicle Infrastructure in Smart Cities
Soruce: CityMoS, 2022

This figure illustrates the digital twin-based simulation cycle of electric vehicle infrastructure in smart cities. The model comprises four core components (CityMos, 2022):

- Behavioural Modelling: Users' vehicle usage, charging preferences, and mobility habits are analysed.
- Charging Station Placement Optimization: Using behavioural data, the locations of charging stations are optimized for energy efficiency and accessibility.
- Electric Grid Simulation: The impacts of increasing charging demand on the power grid are assessed, and potential load-balancing strategies are tested.
- Mobility and Charging Simulation: Vehicle traffic, charging station utilization, and energy distribution are simulated holistically.

Bidirectional data flows exist between these components. The model aims to optimize the interaction between urban mobility, energy infrastructure, and user behaviours in real time, thereby creating a more sustainable and efficient urban transportation system.

3.3. Case Studies from Germany

Germany represents a context in which digital twin technology has been addressed through concrete applications in urban planning, participatory processes, and urban resilience. An academic case study focusing on the town of Herrenberg demonstrates that digital twins are not limited to spatial models but function as tools that strengthen participatory processes, enable the simulation of complex urban data, and support decision-making (Dembski et al., 2020). The study shows that the digital twin integrates 3D modelling, mobility simulations, air-flow simulations, and social data layers into a coherent system, thereby contributing to urban planning processes. The digital twin approach developed for the city of Herrenberg consists of five main components: a detailed three-dimensional model of the physical environment, a street network model, an urban mobility simulation, a wind-flow simulation, and quantitative and qualitative social data derived from volunteered geographic information (VGI) (Dembski et al., 2020).

3.3.1. Connected urban twins

The Connected Urban Twins (CUT) project is a collaborative programme conducted between the cities of Hamburg, Leipzig, and Munich in Germany between 2021 and 2025. The project aims to introduce innovative, data-driven solutions to urban planning and resilience processes through the development of Urban Data Platforms and Urban Digital Twins. For example, traffic flow modelling, simulation of energy infrastructure and consumption, and air quality monitoring can be carried out more effectively through digital twins, supporting the development of pre-disaster risk assessment and intervention strategies (connectedurbantwins.de). These models are particularly relevant for addressing climate-related risks, infrastructure resilience, and public participation (connectedurbantwins.de).

3.4. Case Studies from Netherlands

Studies conducted in the Netherlands indicate that digital twin technologies hold significant potential for enhancing urban resilience, particularly with respect to water-related hazards. Therias and Rafiee (2023) identify the Netherlands as one of the leading countries where city digital twins are used in a systematic and advanced manner to support urban resilience objectives. The Dutch context is frequently referenced to illustrate the strategic role of digital twins in addressing challenges related to climate change, water management, and flood risk. In this setting, digital twins are defined not merely as three-dimensional representations of urban form but as dynamic platforms that enable the integrated modelling of multiple urban systems, including hydrological systems, infrastructure networks, and land-use patterns. The authors emphasise that in Dutch cities located below sea level and exposed to high flood risk, digital twins have become an important instrument for the development of climate adaptation and risk reduction policies.

Andriessen et al. (2024), in their study conducted in the city of Rotterdam, demonstrate that three-dimensional city models provide an effective means for assessing flood risk and analysing its spatial impacts. The study highlights that CityGML-based 3D city models do not serve solely as geometric representations; rather, when enriched with semantic information such as building use, number of storeys, and infrastructure type, they can be transformed into a functional urban digital twin framework. In this research, flood scenarios were integrated with the 3D city model to analyse which buildings, infrastructure elements, and urban functions are at risk under different water-level conditions. This approach enables the assessment of not only the physical damage caused by floods but also their impacts on urban functionality. In particular, the vulnerability of critical infrastructures such as healthcare, transportation, and energy systems to flood events was made visible through semantic modelling (Andriessen et al., 2024).

3.5. Case Studies from Türkiye

The "3D Topography and Building Model Creation Project in Urban Settlements and Development Areas," conducted by the Ministry of Environment, Urbanization and Climate Change of the Republic of Türkiye, aims to create three-dimensional digital twins of all cities (MoEUCC, 2019). Within the scope of the project, approximately 12 million residential units covering an area of 40,000 square kilometers were digitally modelled using aerial photographs obtained through the Orthophoto Project and ground control points (MoEUCC, 2019). Developed through domestic software solutions, this system enables multi-faceted spatial analyses, including pre-disaster risk assessments, detection of non-compliant structures, determination of solar potential in cities, and identification of deficiencies in green spaces (MoEUCC, 2019).

The nationwide digital twin project provides a comprehensive decision support infrastructure for urban planning processes such as zoning, transportation, energy efficiency, and environmental management through the creation of three-dimensional digital models of cities. By modelling flood simulations and other disaster scenarios, the project allows for the early detection of potential risks, thereby increasing cities' resilience to disasters, supporting sustainable development goals, and promoting a data-driven management approach across the country (MoEUCC, 2019).

Yıkıcı (2023) analyzed international examples of digital twin city applications and examined current trends in Türkiye. According to this study, although digital twin technologies in Türkiye are currently implemented in a limited number of pilot projects, they possess significant potential, especially in disaster management and urban risk prediction. However, challenges such as data infrastructure, technical standards, and institutional capacity remain, limiting widespread adoption (Yıkıcı, 2023). Thus, while digital twin city applications in Türkiye are still developing, they can be considered a strategic tool both for disaster preparedness and for enhancing urban planning processes (Yıkıcı, 2023).

In recent years, digital twin technology in Türkiye has begun to be utilized by public institutions and local governments as part of smart city strategies, disaster management planning, and the strengthening of spatial decision support systems. These technologies are based on creating three-dimensional (3D) spatial models of cities, transferring the physical environment into digital format, and supporting it with real-time data. This enables the simulation of potential disaster scenarios, optimization of infrastructure management, and informed sustainable planning decisions.

Various institutions, organizations, and private entities produce digital twins in Türkiye, often under project-specific initiatives. The following are examples of institutions and projects engaged in digital twin development:

- General Directorate of Land Registry and Cadastre
  - "3D City Models and Cadastre Project"
- Ministry of Industry and Technology
  - Digital twin and smart city infrastructures for cities under the framework of "Twin Transformation"
  - "Twin Transformation Internet Portal"
- Ministry of Environment, Urbanization and Climate Change
  - 3D Topography and Building Model Project for 81 Provincial Centers
  - "3D Topography and Building Model Creation Project in Urban Settlements and Development Areas"
- Disaster and Emergency Management Authority
- Metropolitan / District Municipalities

3.5.1. Denizli

Within the scope of the project conducted by the Ministry of Environment, Urbanization and Climate Change, digital twin data for Denizli province are being updated and expanded (MoEUCC, 2022). High-resolution 3D models of the city were created using drone technologies and integrated with cadastral, address, and zoning data. The primary aim of the project is to monitor and manage urban spaces comprehensively. The resulting digital twin enables applications such as modeling disaster risk scenarios, identifying at-risk structures, and spatially testing pre-disaster intervention plans. In this way, the digital twin serves as a proactive decision support tool to enhance urban resilience and disaster management (MoEUCC, 2022).

3.5.2. Kastamonu

The digital twin project in Kastamonu, initiated by local entrepreneurs, represents a pilot project exemplary for Türkiye (Presidency Directorate of Communications, 2025). The city's building stock, roads, parcels, and infrastructure elements have been transferred into a three-dimensional environment. This work aims to enable data-driven decision-making in urban spatial planning processes. Its core functions include identifying risk-prone areas during potential disasters, optimizing evacuation routes, and testing response plans. The project is currently in its pilot phase (Presidency Directorate of Communications, 2025).

TwinUp is a notable public-private collaboration model in the development of urban digital twin capacity. With real-time data integration, scalable 3D models, and simulation capabilities, TwinUp provides spatial decision support in city management, contributing directly to transportation, environmental, infrastructure, disaster management, and urban resilience processes (TwinUp, 2025). Digital twin projects in Konya and Kastamonu are being implemented through TwinUp.

3.5.3. Kayseri

The "3D City Models and Cadastre Project" led by the General Directorate of Land Registry and Cadastre is a nationwide initiative pioneering digital twin production processes (TKGM, 2025). Kayseri has been selected as a key pilot province. The Kayseri Metropolitan Municipality held a "Digital Twin Meeting," focusing on the advantages digital twins offer in infrastructure management, urban planning, data analytics, scenario simulations, and disaster preparedness. By transferring multi-layered geographical, zoning, and urban life data into a digital environment, municipal authorities aim to strengthen decision-making processes. This approach is expected to contribute to making Kayseri both sustainable and resilient (Kayseri Municipality, 2025).

3.5.4. Konya

The Digital Twin City Project in Konya is one of the pioneering applications of urban-scale digital twin technology in Türkiye. Conducted by TwinUp, the

project aims to monitor and analyse the city's infrastructure, transportation, energy, disaster management, and environmental indicators in an integrated manner. The developed digital twin platform models Konya's physical elements in 3D, enabling simulations of urban processes and scenario analyses (TwinUp, 2025).

The system also functions as a spatial decision support system. Integration of real-time data allows for the development of risk scenarios related to potential disasters, enabling more effective evaluation of intervention plans before, during, and after incidents. The project is thus an innovative application that integrates urban resilience with digital transformation processes. Moreover, virtual reality (VR)-based visualization features allow for transparent communication of urban planning and transformation processes to the public, promoting participatory governance. The long-term objective of this digital twin infrastructure is to support sustainable urban policies and the establishment of a data-driven planning culture (TwinUp, 2025) (Figure 4).

Figure 4. Digital Twin Visualization of Konya
Source: TwinUp, 2025

3D modeling work is also ongoing in İzmir, Amasya, and Kütahya. According to the Ministry of Environment, Urbanization and Climate Change (MoEUCC), digital twin requirements and planned application areas have been assessed for these provinces.

4. Urban Resilience in the Context of Smart City Technologies and Digital Twins

Conceptual studies frequently reveal a strong link between smart city planning and urban resilience. Almulhim (2025) highlights the connection between smart cities and resilient cities through a comprehensive literature review. The research findings state that smart systems can make cities more resilient to environmental, social, and economic risks (Almulhim, 2025). In this context, smart city applications contribute to the development of resilience mechanisms against disasters and climate change (Almulhim, 2025).

The integration of data, predictive models, and digital twin technologies plays an important role in increasing the resilience of smart cities (Gkontzis et al., 2024). Gkontzis et al. (2024) define smart cities as innovative models that aim for urban development through data-based systems and digital twin technologies. Digital twin technology provides a new method to monitor urban disaster risks and support preventive decision-making (Du, 2024).

Fuller et al. (2020) explain the relationship between smart cities and resilience through IoT-based data analytics and digital twin technologies. Smart cities can be monitored and analysed in real time thanks to infrastructures equipped with IoT devices and sensors, enabling faster responses to queries (Fuller et al., 2020). In smart cities, digital twins help analyse how city infrastructures will respond in different scenarios by creating virtual models of them (Fuller et al., 2020).

Digital twins have significant impacts in conjunction with smart city technologies. Mylonas et al. (2021) address the resilience of smart cities in their work; digital twins are smart technologies that contribute to resilience (Mylonas et al., 2021). These technologies enable decision-makers to anticipate potential risks in advance through the simulation of different scenarios in planning and disaster management. The study also emphasises that digital twins transform smart cities in terms of resilience. Cities' capacity to adapt to disasters is enhanced through digital models of urban systems such as energy, transport, and

health (Mylonas et al., 2021). It is emphasised that digital twin technologies have become a tool that supports the sustainability and resilience goals of smart cities.

Mohammadi & Taylor (2017) define the concept of digital twins as a new framework that enables a better understanding and management of the complex, multi-layered structures of smart cities. In their work, they treat cities as cyber-physical systems, emphasising that the transfer of data from the physical environment to the virtual environment makes urban processes both traceable and predictable. In particular, modelling spatiotemporal data flows reveals the connections between cities' infrastructure, transport, energy, and social interaction networks, enabling the dynamic analysis of these relationships (Mohammadi & Taylor, 2017). Thanks to digital twins, cities are transformed into environments where simulations can be performed in advance for unexpected situations such as disasters or intense population movements. This digital representation can analyse not only the performance of urban infrastructure but also the spatial and temporal variability of human behaviour (Mylonas et al., 2021).

In their study, Ford & Wolf (2020) examined how digital twin systems can be used to increase the disaster management capacity of smart cities. The authors emphasise that by continuously monitoring city infrastructure (e.g., transport, energy, water, and communication networks) with sensors and transferring this data to a digital environment, disaster risks can be predicted in advance and faster, data-driven decisions can be made during crises (Ford & Wolf, 2020). The study also states that integrating digital twin systems with decision support mechanisms in urban planning provides significant advantages in resource management, emergency planning, and post-disaster recovery processes. Exploiting smart cities with digital twins requires the integration of sensing and simulation across diverse infrastructure systems (Ford & Wolf, 2020). Thus, digital twins transform smart cities into not only smart and efficient but also resilient urban systems (Ford & Wolf, 2020) (Figure 5).
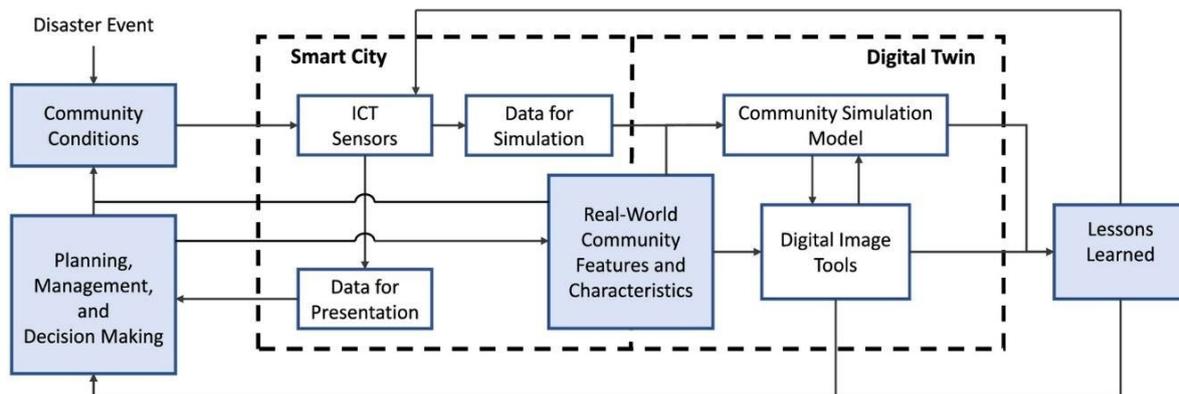

Figure 5. Community Disaster Management Model with Digital Twin in Smart Cities
Sorurce: Ford&Wolf, 2020

Figure 5 illustrates the relationship between the smart city digital twin system and disaster management. This model establishes a system in which the smart city collects data from sensors in the city, the digital twin processes this data, and decision-making mechanisms utilizing community information work together to enable faster and more accurate disaster management. According to Ford and Wolf (2020), community-based disaster management provides a valuable foundation for strengthening smart city digital twin frameworks.

Cities face increasing risks of natural and human-induced disasters, such as floods, earthquakes, and technological accidents. Traditional disaster management methods may be insufficient for dynamic urban systems. The integration of smart cities with digital twin technologies provides a proactive framework for urban resilience. By creating virtual copies of physical city infrastructures, authorities can simulate disaster scenarios, assess vulnerabilities,

and optimize emergency response strategies (Ford & Wolf, 2020).

In smart cities, next-generation information technologies that enable effective use of complex data—such as big data, digital twins, the Internet of Things (IoT), cloud computing, machine learning, Building Information Modelling (BIM), living labs, and blockchain—are becoming increasingly significant (Yalçıner Ercoşkun & Özel Mazlum, 2025). Digital twin technology allows continuous monitoring of physical systems through IoT devices and sensors, forming the basis for predictive analytics. With advancements in big data techniques, IoT, cloud computing, and artificial intelligence algorithms, digital twin technology has entered a rapid development phase and is recognized as one of the ten most promising technologies (Yang et al., 2021). Digital twins are widely applied in various fields, including industry, smart cities, and smart healthcare, and remain a heavily researched area (Yang et al., 2021). In the litera-

ture, the use of digital twins in smart cities primarily focuses on agriculture, urban transportation, urban health management, and security (Yang et al., 2021). In urban transportation, digital twins contribute significantly to driving safety and railway management. Cloud-based data integration enables the development of driver-assistance systems, and digital twin frameworks can be applied for autonomous vehicle simulation (Yang et al., 2021). In the domains of security and disaster management, digital twins are an effective tool for evaluating city vulnerability, infrastructure management, and disaster scenario as-

sessment. Additionally, in urban construction, digital twins optimize anomaly detection and data management processes based on the operational status of assets (Yang et al., 2021).

4.1. Digital Twin-Based Smart City Layers

The digital twin smart city is built upon a series of information layers in the city. The digital twin-based smart city model consists of six core components reflecting the multi-layered structure of urban systems (Table 1).

Layer	Layer Name	Description
Layer 0	Terrain	Contains the city's fundamental geographic and topographic structure. Provides the basis for positioning physical infrastructure and buildings.
Layer 1	Buildings	Represents existing buildings with BIM (Building Information Modelling) data. Shows physical characteristics, usage patterns, and functional distributions of structures.
Layer 2	Infrastructure	Encompasses the city's essential physical and organizational systems, including service networks such as water, energy, transportation, and communication infrastructures.
Layer 3	Mobility	Simulates movement of people, vehicles, and goods within the urban area. Traffic flow, public transport systems, and logistics processes are modelled in this layer.
Layer 4	Virtual Smart City	Collects data from IoT devices, sensors, and connected systems to manage city services. Acquired data is transferred to decision support systems and performance analysis processes.
Layer 5	Virtual Digital Twin	Uses data from Layer 4 to create digital simulations of urban systems. Tests alternative scenarios, forecasts potential future conditions, and supports cognitive, adaptive decision-making mechanisms in smart cities.

Source: White et al., 2021

In this model, the first five layers progressively define the physical and digital elements of the city. These layers, consisting of terrain structure, buildings, infrastructure systems, urban mobility, and IoT devices, are built upon each other to create a comprehensive digital representation of the city (White et al., 2021). The structure, defined as the 'Digital Layer,' continuously collects data through sensors, IoT devices, and information systems throughout the city and transmits this data to the 'Virtual Layer,' i.e., the digital twin (White et al., 2021). The digital twin uses the data obtained to perform advanced simulations on mobility optimisation, building placement, or the design of renewable energy systems such as offshore wind turbines (White et al., 2021). These simulation results are fed back into the physical world through the layers of the model and used as a decision support mechanism in smart city management, thus providing a holistic structure that both supports data-driven urban planning and enables cities to achieve their sustainability, efficiency, and resilience goals (White et al., 2021).

Digital twin-based smart cities evolve through different layers; the first layer contains basic city-related information (e.g., street and building names), while the second layer presents three-dimensional models of the city based on this data (Babaoğlu & Memiş, 2024). The third layer enables real-time data transmission through various technologies, while the final layer is proposed as a visualization layer targeting augmented reality and Metaverse integration (Babaoğlu & Memiş, 2024). The digital twin technology created from these layers' highlights three primary functions: observation/sensing, assessment/analysis, and solution generation/alternative provision (Babaoğlu & Memiş, 2024). In addition, it demonstrates applications in data management, visualization, situational awareness, planning and forecasting, integration, and collaboration (Babaoğlu & Memiş, 2024). These identified themes contribute to understanding the current status and potential of digital twin technologies in cities, thereby maximizing the benefits of digital twins in urban areas.

The digital twin-based smart city platform developed by Dani et al. (2023) enables more holistic, predictive, and data-driven decision-making in urban management areas such as disaster management, traffic congestion optimization, energy efficiency

planning, and environmental sustainability through multi-layered data integration and real-time analytical capabilities. This structure establishes bidirectional data flows between physical city components and virtual models, allowing managers to model potential risks in advance and develop effective intervention strategies under different scenarios. Citi-

zen feedback loops are essential for the continuous improvement of digital twin applications in smart cities (White et al., 2024). By integrating citizen input into virtual models, digital twins can better reflect community needs and improve urban planning outcomes (White et al., 2024).
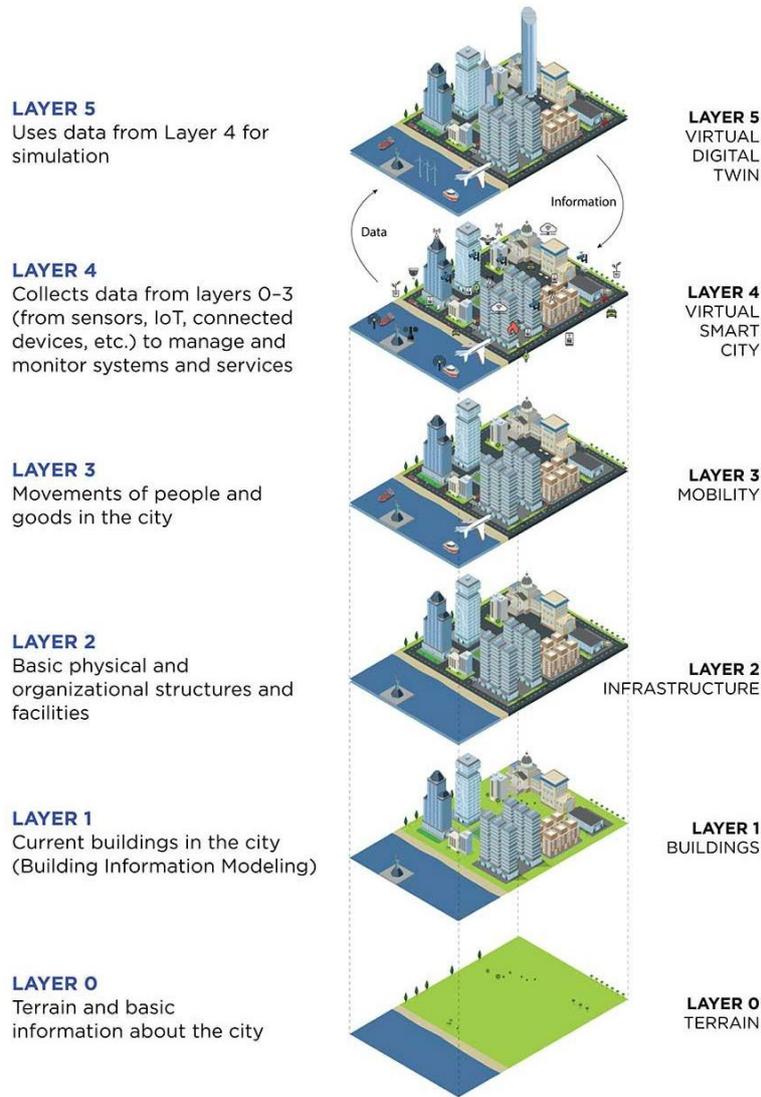

Figure 6. Digital Twin-Based Smart City Layers
Source: White et al., 2021

This visual (Figure 6) presents a schematic explaining the multi-layered structure of city digital twins and smart cities. Each layer represents data flow between physical and virtual environments and the simulation of urban systems. This schematic demonstrates that digital twins act as a data-driven bridge between the physical and virtual city. It provides the necessary infrastructure for decision support systems in areas such as disaster management, infrastructure planning, energy optimization, traffic flows, and simulations. Inter-layer data flow is crucial for enhancing the resilience and sustainability capacity of cities.

4.2. Urban Resilience Criteria: The Contribution of Digital Twin Technologies to Resilience Criteria

Studies based on literature reviews addressing the definition and core characteristics of urban resilience demonstrate that urban resilience exhibits a multidimensional structure and encompasses not only physical robustness but also capacities for adaptation and transformation (Dincer & Yalçıner Ercoşkun, 2021). In this context, Table 2 developed by Dincer and Ercoşkun summarises the key characteristics of urban resilience that are prominent in the literature:

Table 2. Resilience Definition and Characteristics

Resilience Characteristic	Description
Robustness	The capacity of systems to maintain structural integrity and essential functions in the face of external shocks and sudden pressures.
Recovery Speed	The ability of a system to return to its previous functions within a short period following a crisis or disruption.
Flexibility	The capacity to adapt to changing conditions and respond to different scenarios.
Adaptive Capacity	The ability of systems to reorganise their behaviours and structures over time through learning processes.
Learning Capacity	The capability to derive lessons from past crises and become better prepared for future risks.
Transformative Capacity	The potential of a system to fundamentally restructure itself when existing structures prove insufficient.
Continuity	The ability to maintain essential services and functions without interruption during and after a crisis.
Multidimensionality	The inclusion of social, economic, environmental, and governance components alongside physical dimensions of resilience.
Connectivity	A high level of interaction and coordination among system components.
Inclusiveness	The inclusion of all segments of society, including vulnerable groups, in resilience processes.

Source: Dinçer & Ercoşkun, 2021

Urban resilience is a dynamic concept that requires cities to be evaluated through multiple dimensions, including the physical environment, environmental–climatic conditions, and socio-economic structures. Dincer and Yalçıner Ercoşkun (2024) conceptualise urban resilience as the capacity of cities to sustain essential functions, adapt, and recover in the face of shocks and long-term stresses, emphasising that this capacity should be integrated into planning processes through measurable criteria. In their study, resilience criteria are classified under three main categories: physical environment (impervious surfaces, green space ratio, disaster risk), environment and climate (temperature, precipitation, air quality, consumption), and socio-economic structure (population density, vulnerable groups, governance, and economic indicators). Addressing these criteria in an integrated manner enables the identification of urban vulnerabilities and provides a comprehensive framework for spatial decision-making processes.

Vasilevska and Slavković (2024) approach urban resilience as a holistic concept that encompasses continuity, adaptive capacity, and transformative capacity in the face of multiple shocks and long-term stresses. Their study evaluates urban resilience criteria within the framework of physical infrastructure and spatial structure, socio-economic systems, environmental components, and governance capacity, emphasising the strong interconnections among these criteria. The authors argue that resilience is not limited to post-disaster recovery but also includes cities' abilities to learn and adapt to future uncertainties.

This perspective necessitates the consideration of urban resilience criteria as dynamic and monitorable processes rather than static indicators (Vasilevska & Slavković, 2024).

Therias and Rafiee (2023) identify urban resilience as one of the most meaningful application areas of digital twins, particularly emphasising their importance in processes such as climate change adaptation, disaster risk reduction, and the testing of emergency scenarios. Digital twin technologies contribute significantly to planning processes by providing a comprehensive analytical environment for monitoring and evaluating urban resilience criteria. Supported by geographic information systems, sensor-based data, and real-time spatial analyses, digital twins are capable of simultaneously representing the physical, environmental, and socio-economic components of urban systems, thereby enabling the anticipation of risks before they materialise. The hybrid modeling architecture proposed by Yun et al. (2022) enables highly accurate disaster predictions by combining real-time sensor data with historical event data, thereby strengthening preparedness and rapid response processes against disasters. This feature positively contributes to the shock adaptation and recovery capacity of systems, which is one of the critical elements of urban resilience. Similarly, Zheng et al. (2019) emphasize the two-way data flow between physical and virtual models in digital twins, demonstrating that this technology supports decision-making processes through dynamic scenario simulation and forward-looking behavior prediction.

5. Findings

Literature findings indicate that digital twins significantly enhance the accuracy of risk analyses in disaster management processes. The primary reason for this is that more up-to-date modelling can be performed through the integration of real-time sensor data and comprehensive spatial inventories. This integration increases predictive capacity, enabling intervention plans to be prepared in a more targeted and effective manner. Digital twins also allow for the simulation of scenarios such as floods, infrastructure failures, and traffic congestions, enabling different intervention strategies to be tested in advance. This feature contributes to disaster preparedness, real-time disaster management, and prioritization in transportation planning.

When successful digital twin applications are examined, as seen in projects such as Tokyo, Virtual Singapore, and PLATEAU, multi-layered data sets are utilized, and dynamic databases are created for different decision-making scenarios during disasters. Digital twin applications, particularly due to their capacity to anticipate which points in infrastructure may become nonfunctional, optimize the prioritization of interventions and the allocation of resources. Consequently, both logistical burdens are reduced, and intervention times are shortened. Existing reports and pilot project results demonstrate that this improvement is not merely theoretical but is also confirmed by practical outputs.

Furthermore, as in the Tokyo example, some digital twin projects incorporate layers of social vulnerability into their models. When socio-demographic variables such as elderly population density, transportation accessibility, women, and persons with special needs are included in the system, disaster response plans are shaped not only around physical infrastructure but also in accordance with social justice principles. This clearly indicates that social vulnerabilities must be analysed spatially in disaster management planning.

Academic studies and applications examined through examples from Germany and the Netherlands demonstrate that digital twin technologies offer a holistic planning approach to developing urban resilience. In Germany, the Herrenberg case study and the Connected Urban Twins (CUT) project demonstrate that digital twins strengthen participatory planning processes by integrating three-dimensional spatial models, mobility and environmental simulations, and social data layers. These applications support the effectiveness of digital twins in terms of infrastructure resilience, climate-related risks, and pre-disaster scenario development. Examples from the Netherlands show that digital twins play a strategic role, particularly in the context of water management and flood risks. As in the Rotterdam example, the integration of flood scenarios with semantically enriched 3D city models based on CityGML enables the analysis of not only physical damage but also the vulnerability of critical urban functions such as health, transportation, and energy. These findings reveal that digital twin technologies bring urban resilience into a multidimensional, foresight-based, and proactive planning framework.

In the Turkish context; Denizli, Kastamonu, Kayseri, and Konya provide an important starting point for the integration of digital twins with disaster management. However, there are limitations, including deficiencies in collaboration processes, integration challenges, insufficient inter-institutional data sharing, and technical issues. Generally, key challenges in the widespread adoption of digital twins include data privacy, cybersecurity, data quality and compatibility issues, lack of an institutional sharing culture, funding constraints, and insufficient qualified human resources.

Studies examining examples from different countries reveal that digital twin technologies do not have a uniform application area in the context of urban resilience. Instead, they have developed different usage patterns depending on the risks each country faces and their institutional structures. Disaster types, planning priorities, and technical capacity levels are among the key factors determining which urban systems digital twins focus on and for what purposes they are used. This necessitates a comparative analysis of the contribution of digital twins to urban resilience across countries. In this context, Table 3 presents the risks targeted by digital twin technologies in selected countries, their current usage status, and their contributions to urban resilience within a comprehensive framework.

Table 3. Comparison of Digital Twin Applications and Their Contribution to Urban Resilience Across Countries

Country	Focused Risks	Current State of Use	Contribution to Urban Resilience
Netherlands	Flooding, pluvial flooding, sea-level rise, climate change	Digital twins are actively used in water management, flood scenario modelling, and infrastructure and land-use planning.	Development of climate adaptation strategies, reduction of flood risks, and enhancement of the long-term resilience of infrastructure systems
Japan	Earthquakes, tsunamis, typhoons, flooding	Digital twins are used for pre-disaster risk analysis, disaster-time simulation, and post-disaster damage assessment.	Strengthening early warning systems, enhancing rapid response capacity, and improving post-disaster recovery processes

Singapore	Extreme rainfall, flash floods, sea-level rise, risks related to urban density	Digital twins are used in urban infrastructure management, flood modelling, microclimate analyses, and smart city applications.	Real-time monitoring of infrastructure systems, enhancement of climate adaptation capacity, and anticipatory management of risks in high-density urban areas
Germany	Urban heat island effect, air pollution, transport-related risks	Digital twins are used in urban planning, environmental analyses, and participatory decision-making processes.	Improvement of environmental quality, support for sustainable transport policies, and strengthening urban resilience through public participation
Türkiye	Earthquakes, flooding, pluvial flooding	Digital twins are primarily used for 3D city models, spatial analyses, and pilot-scale disaster scenarios. Applications are mostly project-based.	Early identification of disaster risks, support for planning processes, and development of data-driven decision-making capacity

Source: Table by the Authors

The comparative assessment in Table 3 was created to examine, within a comprehensive framework, which risk areas digital twin technologies focus on in different countries in the context of urban resilience, their current usage practices, and the contributions these applications make to urban systems. The findings reveal that digital twin applications have developed around different priorities based on countries' physical geography, the predominant types of disasters they face, and their administrative capacities. In the cases of the Netherlands and Singapore, digital twins are used primarily for water management, modeling flood risks, and supporting climate change adaptation policies; in this context, urban infrastructure components are addressed through an integrated approach. In Japan, digital twin applications play a significant role in supporting risk analyses, early warning mechanisms, and response processes for sudden and high-impact disasters such as earthquakes and tsunamis. The German example shows that digital twins go beyond disaster-focused use and are integrated into environmental quality, urban climate, and participatory planning processes. In contrast, applications in Türkiye are largely limited to three-dimensional city models and project-based studies conducted on a limited scale; the use of digital twins as an integrated, continuous urban management tool is still in its infancy. Overall, the findings reveal that the contribution of digital twin technologies to urban resilience cannot be explained solely by technical capacity; it must be considered in conjunction with institutional structure, data integration, and policy-making processes.

In conclusion, the existing literature and field applications demonstrate that digital twin technologies have a high level of applicability in disaster management, and their most effective use emerges when multi-layered spatial data integration, real-time sensor flow, and planner-operator interfaces are fully integrated. Although significant infrastructure steps have been taken in Türkiye in this area, progress in inter-institutional data sharing, technical standardi-

zation, and capacity development will enable digital twins to become a sustainable decision support tool in disaster management processes.

6. Conclusion and Recommendations

The digital twin model created in cities is built on three-dimensional data generated at the building and parcel level. This structure supports decision-makers in areas such as urban planning, land management, energy efficiency, transportation, and infrastructure development. In disaster management, the model is expected to facilitate analyses related to risk assessment, building damage estimation, prioritization of interventions, and post-disaster recovery. In this way, the digital twin serves both as a spatial decision-support tool and as a planning instrument that enhances urban resilience.

The success of disaster management processes depends not only on the accuracy of physical infrastructure data but also on the proper analysis of the social, economic, and environmental characteristics of communities. Therefore, digital infrastructures used in disaster management should have strong capabilities for reliable data collection, integration, and analysis. Smart city technologies provide real-time data flow to administrators through systems capable of maintaining sustainable performance even under disaster conditions. Simulation models integrated with digital twins use these data to assess the potential impacts of different scenarios in advance. This approach makes it possible to better anticipate the outcomes of disaster management decisions on community systems and to evaluate administrative processes in a more holistic manner.

Digital twins and 3D models, by representing spatial and infrastructural data in a virtual environment, offer major advantages for planning and disaster management processes. They reduce the need for fieldwork and physical measurement, saving both time and cost. Moreover, the ability to test different scenarios through simulations contributes to faster

and more effective decision-making during planning and response stages. By integrating live data streams in addition to static information, digital twins help ensure the efficient use of resources and support the achievement of sustainable urban development goals.

For these technologies to be implemented effectively, it is essential to establish data-sharing mechanisms and develop technical standards among institutions. Ensuring interoperability between data produced by AFAD, the Ministry of Environment, Urbanization and Climate Change, the General Directorate of Land Registry and Cadastre, and local governments would improve the efficiency of digital twin applications. Additionally, enhancing digital literacy within local governments and strengthening planners' skills in using these technologies are crucial for sustainable practices.

Incorporating digital twin approaches into spatial planning legislation and disaster management strategy documents will help integrate these technologies into institutional decision-making processes. This integration will strengthen a data-driven and foresight-oriented planning culture. Furthermore, by providing open interfaces that allow public access, digital twin platforms can promote citizen participation, making it easier for residents to engage in decision-making processes and increasing social awareness and resilience.

Although the digital twin and 3D modeling projects implemented in Türkiye are an important start, these efforts need to be expanded to enhance disaster resilience. In particular, using digital twins to quickly and accurately calculate the amount of debris generated after earthquakes could improve the effectiveness of response plans and optimize logistics operations. This would save time during clean-up and evacuation efforts while reducing environmental and economic losses.

In conclusion, digital twin systems supported by multi-layered data integration and real-time sensor flows hold significant potential for increasing the resilience of cities in Türkiye and building sustainable decision-support infrastructures. For these technologies to become a permanent tool in the long term, public–private partnerships and the activation of international funding mechanisms are essential. In this way, digital twin applications will not remain merely a technical innovation but will become a planning tool that directly contributes to urban resilience and sustainable development.

References

Alam, K. M., & El Saddik, A. (2017). C2PS: A digital twin architecture reference model for the cloud-based cyber-physical systems. IEEE Access, 5, 2050–2062. https://doi.org/10.1109/ACCESS.2017.2657006

Almulhim, A. I. (2025). Building urban resilience through smart city planning: A systematic literature review. Smart Cities, 8(1), 1–18.

Andriessen, L., Agugiaro, G., Borgers, A., & Pauwels, P. (2024). Semantic 3D city models as support for urban flood resilience: experiences from Rotterdam. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 10, 5–12.

Babaoğlu, C., & Memiş, L. (2024). Dijital ikiz ve akıllı şehirler. Ankara: Seta Yayınları.

Batty, M. (2018). Digital twins. Environment and Planning B: Urban Analytics and City Science, 45(5), 817–820.

Boschert, S., & Rosen, R. (2016). Digital twin—the simulation aspect. In S. Boschert & R. Rosen (Eds.), Mechatronic futures: Challenges and solutions for mechatronic systems and their designers (pp. 59–74). Cham: Springer International Publishing.

Chen, Y. (2017). Integrated and intelligent manufacturing: Perspectives and enablers. Engineering, 3(5), 588–595.

Çubukçu, Z., Memiş, L., & Babaoğlu, C. (2024). Akıllı şehirlerde acil durum ve afet yönetiminde dijital ikiz teknolojisi: Potansiyeller ve uygulamalar. TYB Akademi Dil Edebiyat ve Sosyal Bilimler Dergisi, 40, 75–92. (Sayı ve sayfa aralığı eklendi – tahmini; gerçek değer varsa düzeltilmeli)

Dani, A. A. H., Supangkat, S. H., Lubis, F. F., Nugraha, I. G. B. B., Kinanda, R., & Rizkia, I. (2023). Development of a smart city platform based on digital twin technology for monitoring and supporting decision-making. Sustainability, 15(18), 14002. https://doi.org/10.3390/su151814002

Dembski, F., Wössner, U., Letzgus, M., Ruddat, M., & Yamu, C. (2020). Urban digital twins for smart cities and citizens: The case study of Herrenberg, Germany. Sustainability, 12(6), 2307.

Dincer, Ş. E., & Ercoşkun, Ö. Y. (2021). Kent planlamada yeni bir yöntem önerisi: Kentsel dirençlilik endeksi. Resilience, 5(2), 159–172.

Dincer, Ş. E., & Ercoşkun, Ö. Y. (2024). Urban resilience index study on Ankara metropolitan area. ICONARP International Journal of Architecture and Planning, 12(2), 504–532.

Du, Z. (2024). Technical feasibility analysis of digital twin technology in the field of urban disaster prevention. Applied and Computational Engineering, 82(2), 193–198.

Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. IEEE Access, 8, 108952–108971.

Gkontzis, A. F., Kotsiantis, S., Feretzakis, G., & Verykios, V. S. (2024). Enhancing urban resilience: Smart city data analyses, forecasts, and digital twin techniques at the neighborhood level. Future Internet, 16(2), 47.

Koshimura, S., Mori, N., Chikasada, N., Udo, K., Ninomiya, J., Okumura, Y., & Mas, E. (2025). Digital twin paradigm for coastal disaster risk reduction and resilience. In Probabilistic Tsunami Hazard and Risk Analysis (pp. 543–559). Elsevier.

Mohammadi, N., & Taylor, J. E. (2017, November). Smart city digital twins. In 2017 IEEE Symposium Series on Computational Intelligence (SSCI) (pp. 1–5). IEEE.

Mylonas, G., Kalogeras, A., Kalogeras, G., Anagnostopoulos, C., Alexakos, C., & Muñoz, L. (2021). Digital twins from smart manufacturing to smart cities: A survey. IEEE Access, 9, 143222–143249.

Ölmez, M. (2025). Yerel sürdürülebilirlikte dijital ikiz teknolojisi ve doğal afetleri önlemede etkisi: Japonya örneği [Digital twin technology in local sustainability and its impact on natural disaster prevention: The case of Japan]. İşletme, 6(1), 103–127

Pang, J., Huang, Y., Xie, Z., Li, J., & Cai, Z. (2021). Collaborative city digital twin for the COVID-19 pandemic: A federated learning solution. Tsinghua Science and Technology, 26(5), 759–771.

Radanliev, P., De Roure, D., Nicolescu, R., Huth, M., & Santos, O. (2022). Digital twins: Artificial intelligence and the IoT cyber-physical systems in Industry 4.0. International Journal of Intelligent Robotics and Applications, 6(1), 171–185.

Supianto, A. A., Nasar, W., Aspen, D. M., Hasan, A., Karlsen, A. S. T., & Torres, R. D. S. (2024). An urban digital twin framework for reference and planning. IEEE Access, 12, 152444–152465.

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Tao, F., Zhang, H., Liu, A., & Nee, A. Y. (2018). Digital twin in industry: State of the art. IEEE Transactions on Industrial Informatics, 15(4), 2405–2415.

Tao, F., Zhang, M., & Nee, A. Y. C. (2019). Digital twin driven smart manufacturing. London: Academic Press.

Therias, A., & Rafiee, A. (2023). City digital twins for urban resilience. International Journal of Digital Earth, 16(2), 4164–4190.

Vasilevska, L., & Slavković, M. (2024). Urban resilience: Definitions, understanding and conceptualization. Facta Universitatis, Series: Architecture and Civil Engineering, 097–103.

Wang, Y., Yue, Q., Lu, X., Gu, D., Xu, Z., Tian, Y., & Zhang, S. (2024). Digital twin approach for enhancing urban resilience: A cycle between virtual space and the real world. Resilient Cities and Structures, 3, 34–45.

White, G., Zink, A., Codecá, L., & Clarke, S. (2021). A digital twin smart city for citizen feedback. Cities, 110, 103064.

Yalçıner Ercoşkun, Ö., & Özel Mazlum, Z. (2025). Yeni nesil teknolojilerle şekillenen akıllı şehir dönüşümleri: Viyana, Graz, Helsinki ve Singapur örnekleri. Sketch, 7(1).

Yang, D., Karimi, H. R., Kaynak, O., & Yin, S. (2021). Developments of digital twin technologies in industrial, smart city and healthcare sectors: A survey. Complex Engineering Systems, 1(1), Article 1.

Yang, J. (2022, September 29). From concept to practice: Digital twins to city twins. Data Smart City Solutions, Harvard University. https://datasmart.hks.harvard.edu/concept-practice-digital-twins-city-twins

Yıkıcı, A. (2023). Dijital ikiz şehir fenomeni: Dünyadan örnekler ve Türkiye'deki yönelimler. Kent Akademisi, 16(1), 138–163.

Yun, S. J., Kwon, J. W., & Kim, W. T. (2022). A novel digital twin architecture with similarity-based hybrid modeling for supporting dependable disaster management systems. Sensors, 22(13), 4774.

Zheng, Y., Yang, S., & Cheng, H. (2019). An application framework of digital twin and its case study. Journal of Ambient Intelligence and Humanized Computing, 10(3), 1141–1153.

Internet Sources

CityMos. (2022). Singapore integrated transport and energy model. https://citymos.net/case-studies/sitem/ [Erişim: 30 Ekim 2025]

Connected Urban Twins. (n.d.). Our solutions. https://www.connectedurbantwins.de/en/ [Erişim: 25 Aralık 2025]

Çevre, Şehircilik ve İklim Değişikliği Bakanlığı (ÇŞİDB). (2019). Şehirlerin "dijital ikizi" ile afetlere önlem alınacak. https://www.csb.gov.tr/sehirlerin-dijital-ikizi-ile-afetlere-onlem-alinacak-bakanlik-faaliyetleri-29645 [Erişim: 30 Ekim 2025]

Çevre, Şehircilik ve İklim Değişikliği Bakanlığı (ÇŞİDB). (2022). Denizli'nin dijital ikizi güncelleniyor. https://cbs.csb.gov.tr/denizlinin-dijital-ikizi-guncelleniyor-haber-273514?utm [Erişim: 2 Kasım 2025]

Denkeishimbun. (2023). Tsunami disaster digital twin. https://denkeishimbun.co.jp/en/2023/09/post_10053/ [Erişim: 30 Ekim 2025]

Dixon, B. (2018). The technology behind the Thailand cave rescue. https://www.esri.com/about/newsroom/blog/technology-behind-thailand-cave-rescue/ [Erişim: 2 Kasım 2025]

Hokkaido University. (2023). Real-time digital disaster twin system. https://sdgs.hokudai.ac.jp/en/9343/ [Erişim: 30 Ekim 2025]

H2i Singapore. (n.d.). https://www.h2i.sg/ [Erişim: 25 Aralık 2025]

İletişim Başkanlığı. (2025). Kastamonulu genç, ekibiyle Türkiye'de ilke imza attı. https://www.iletisim.gov.tr/turkce/yerel_basin/detay/kastamonulu-genc-ekibiyle-turkiyede-ilke-imza-atti?utm [Erişim: 2 Kasım 2025]

Kayseri Büyükşehir Belediyesi. (2025). Büyükşehir'den Kayseri'nin geleceğini planlayacak dijital ikiz teknolojisi hamlesi. https://www.kayseri.bel.tr/haberler/buyuksehirden-kayserinin-gelecegini-planlayacak-dijital-ikiz-teknolojisi-hamlesi2394223942 [Erişim: 30 Ekim 2025]

One Concern. (n.d.). One Concern launches digital twin in Japan to build climate resilience. https://oneconcern.com/en/news/one-concern-launches-digital-twin-in-japan-to-build-climate-resilience/ [Erişim: 30 Ekim 2025]

Puri, D. (2018). The vital role of technology in the Thai cave rescue mission. https://www.networkworld.com/article/3291787/the-vital-role-of-technology-in-the-thai-cave-rescue-mission.html [Erişim: 30 Ekim 2025]

Smart Nation Singapore. (n.d.). https://www.smartnation.gov.sg/ [Erişim: 25 Aralık 2025]

Sorabatake. (2021). What is a digital twin? Differences from simulations, issues to be solved, examples from companies, countries, and cities, and notable data. https://sorabatake.jp/20125/ [Erişim: 30 Ekim 2025]

TKGM. (2025). https://www.tkgm.gov.tr/istanbul-bm/3-boyutlu-sehir-modelleri-uretimi [Erişim: 30 Ekim 2025]

Tokyo Metropolitan Government. (2024). Tokyo smart resilience platform. https://www.english.metro.tokyo.lg.jp/w/110-101-005910 [Erişim: 30 Ekim 2025]

TwinUp. (2025). Konya digital twin city project. https://twinup.com [Erişim: 30 Ekim 2025]