smart cities

Article

Key Factors Affecting Smart Building Integration into Smart City: Technological Aspects

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Abstract: This research presents key factors influencing smart building integration into smart cities considering the city as a technological system. This paper begins with an overview of the concept of smart buildings, defining their features and discussing the technological advancements driving their development. The frameworks for smart buildings are presented, emphasizing energy efficiency, sustainability, automation, and data analytics. Then, the concept of a smart city and the role of digitalization in its development is explored. The conceptual framework of smart building into a smart city is presented, contributing to understanding the complex process of integrating smart buildings into smart cities. Further research delves into the factors influencing the integration of smart buildings into smart cities, focusing on energy, mobility, water, security systems, and waste management infrastructure domains. Each thematic area is examined, highlighting the importance of integration and the associated challenges and opportunities, based on research in the literature and the analysis of case studies. This enables the identification of 26 factors influencing integration and the synthesis of findings. The findings indicate that the successful integration of smart buildings into smart cities requires attention to multiple factors related to smart energy, smart mobility, smart water, smart security, and smart waste management infrastructures. The results obtained from this research provide valuable insights into the factors influencing smart building integration into a smart city from a technological perspective, enabling stakeholders to make informed decisions and develop strategies paving the way for sustainable, resilient, and efficient urban environments.

Keywords: smart city; smart building; integration; infrastructure; digitalization; smart energy; smart mobility; smart water; smart security systems; smart waste management

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1. Introduction

The rapid urbanization trend is expected to continue, with an estimated 4.6 billion people, accounting for 58% of the global population, residing in urban areas by 2025. This proportion may reach as high as 81% in certain developed regions. This demographic shift presents significant challenges for city planners, who must devise strategies to ensure sustainable living conditions for the growing urban population [1]. One potential solution lies in the development of smart cities and smart buildings. However, the lack of a universally accepted definition for these concepts poses a challenge, making it essential to gain a comprehensive understanding and establish a consensus on the precise meaning of smart cities and smart buildings.

By embracing the principles of smart cities and integrating smart buildings into urban infrastructure, cities can enhance their efficiency, sustainability, and quality of life [2]. The concept of a smart city encompasses various infrastructure domains such as energy, mobility, water, security, and waste management, where digital technologies and data-driven solutions play a crucial role [3]. Similarly, smart buildings embody advanced technologies and systems that optimize resource utilization, improve occupant comfort, and enable efficient operation and management [4].

To fully harness the potential of smart buildings, it is essential to integrate the functionalities proposed by various smart city infrastructure domains and, reciprocally, leverage the recommended features of smart building services to benefit the surrounding systems [2]. However, in many cases, urban infrastructure components operate independently without integration. Therefore, a comprehensive approach is necessary to maximize the capabilities of smart infrastructure and develop smart cities effectively. Collaborative efforts involving scientists from diverse fields, policymakers, planners, managers, civil society representatives, and other relevant stakeholders prove to be advantageous and effective [5,6].

The integration of smart building features suggested by smart city infrastructure domains implies that buildings should be designed to facilitate seamless interaction with existing and anticipated city infrastructure [7]. Potential strategies may involve the integration of intelligent infrastructure within urban areas, such as the convergence of smart buildings with the city's smart grid to optimize energy consumption [8], establishing connections between smart buildings and public transportation to mitigate environmental impact [8–10], or implementing intelligent waste management systems that align with the city's existing waste management infrastructure.

The integration of smart buildings into the existing smart city systems is a topic of increasing interest and importance [11]. As urban populations continue to grow and the demand for resources escalates, it becomes imperative to explore innovative solutions that maximize the utilization of available resources while minimizing their environmental impact [12]. Smart building integration offers a promising avenue for achieving these goals by incorporating advanced technologies, automation, and data-driven systems into the design, construction, and operation of buildings [13].

By adopting an integrated approach and incorporating the suggested features of smart domain infrastructure domains into smart building design [7], cities can capitalize on the synergistic benefits that arise from the harmonious interaction between buildings and their surrounding infrastructure. These strategies enable resource optimization, enhanced sustainability, and improved quality of life for urban residents [14,15].

To address the challenges and complexities associated with the integration of smart buildings into smart cities, this research aims to analyze the key technological factors that influence this integration. By identifying these factors and understanding their implications, policymakers, urban planners, and stakeholders can make informed decisions and develop effective strategies for successful integration. The research will contribute to the existing body of knowledge by providing insights into the multifaceted aspects of smart building integration into a smart city and highlighting the importance of addressing energy efficiency, mobility, water conservation, security, and waste management in the context of smart cities. Ultimately, this research seeks to pave the way for sustainable and resilient urban environments that can cater to the needs of the expanding urban population.

The paper's structure is organized as follows. Firstly, an exploration of the concept of smart building, including the requirements and frameworks for successful implementation is carried out. This is followed by the concept of a smart city, highlighting the importance of digitalization and its impact on various infrastructure domains within a smart city. Subsequently, the paper focuses on the integration of smart buildings into smart cities, presenting a conceptual framework that emphasizes the interdependencies and benefits of integration. To achieve the research aim, an in-depth analysis of relevant research studies, case studies, best practices, and expert opinions was employed. The identified influencing factors on smart building integration into smart cities are then presented and discussed, focusing on key infrastructure areas such as smart energy, smart mobility, smart water, smart security systems, and smart waste management. The analysis of case studies from different geographical areas illustrates the selected set of technological factors affecting smart building integration into smart cities. Finally, the paper concludes with a synthesis of the findings and discussions, identifying common challenges, limitations, and areas for further research. The research outcomes might serve as a source of valuable recommendations for stakeholders involved in smart city development, supporting informed decision making, and promoting advanced urban development.

2. Smart Building

2.1. Concept of Smart Building

The concept of a smart building has gained significant attention in the context of creating sustainable, energy-efficient, and intelligent built environments.

Smart buildings possess several key features that set them apart from traditional buildings. Firstly, they incorporate automated systems for environmental control, including heating, ventilation, air conditioning (HVAC), lighting, and shading. These systems use real-time data from sensors to adjust settings based on occupancy, weather conditions, and energy consumption patterns, leading to energy efficiency and enhanced occupant comfort [16]. Secondly, smart buildings employ advanced building management systems (BMS) that integrate various subsystems and devices into a centralized platform. This allows for centralized monitoring, control, and analysis of building operations, leading to improved operational efficiency, predictive maintenance, and proactive decision making [17].

Moreover, smart buildings leverage data analytics and machine learning algorithms to derive insights from collected data. By analyzing patterns, trends, and anomalies, these buildings can optimize resource utilization, identify energy-saving opportunities, and anticipate maintenance needs [18]. The use of data-driven insights enables continuous improvement and adaptability within smart buildings. The development of smart buildings is driven by various technological advancements. Firstly, the proliferation of sensing technologies and IoT devices has made it possible to collect real-time data on building performance, occupancy, and environmental conditions. These sensors provide valuable inputs for monitoring, control, and optimization strategies [19].

Furthermore, advancements in data analytics and cloud computing enable the processing and storage of vast amounts of data generated by smart buildings. Machine learning algorithms can analyze this data to extract meaningful insights and support decision-making processes [20]. Cloud-based platforms also enable remote access, monitoring, and control of smart building systems, enhancing operational flexibility and scalability [21]. Additionally, the emergence of edge computing and wireless communication technologies facilitates real-time data processing and reduces latency in smart building applications [22]. Edge devices, such as edge servers and gateways, enable local data processing and analysis, enhancing the responsiveness and efficiency of smart building systems.

Smart buildings intelligently control internal environments by integrating building systems on a single network and adapting characteristics of construction materials and façade elements to changing usage and weather conditions. Furthermore, a crucial feature of a smart building is the provision of building services that optimize occupant productivity while simultaneously reducing costs and minimizing environmental impact. Technological advancements in regulating the interior environment have led to the emergence of smart buildings as responsive and controlled environments for inhabitants, companies, and society [23]. The objective of smart buildings is to achieve a state of self-management, learning, prediction, and adaptation without requiring any intervention or awareness from their occupants. Sensors and monitors can expeditiously and autonomously modify ambient temperatures, illumination, shading, energy efficiency, and water usage. One of the applications of the IoT in urban contexts is the utilization of ICT to enhance the quality of life for occupants in smart building environments [24].

2.2. Smart Building Evaluation Frameworks

Smart buildings are designed to meet specific requirements and follow established frameworks that guide their development and operation. One of the primary requirements for smart buildings is energy efficiency. Energy consumption in buildings accounts for a significant portion of global energy use, making energy efficiency a crucial consideration in smart building design [8]. Energy-efficient systems, such as high-performance

HVAC systems, advanced lighting controls, and smart metering, are integrated into smart buildings to minimize energy consumption and reduce environmental impact [25]. Energy performance certification (EPC) is a system that rates the energy efficiency of buildings.

Smart building is considered to compile the features of a sustainable building as well [15]. In this regard, BREEAM, LEED, DGNB, and other national-level frameworks are established to guide the design, implementation, and evaluation of sustainable buildings. The European Commission recently launched LEVEL(s), a framework for sustainable buildings that connects the specific performance of the building to European policy objectives [26].

Automation is another essential aspect of smart building requirements. Automation also enables the implementation of advanced features like adaptive lighting, predictive maintenance, and demand response [27]. Building management systems (BMS) and building automation and control systems (BACS) are used for the integration and interoperability of various building systems, including HVAC, lighting, security, and fire safety [28]. The BMS focuses on centralized monitoring, control, and optimization, enabling the seamless operation of these systems within smart buildings.

In relation to automation and BMS, some frameworks were developed to assess the smartness of buildings, including, for example, the smart readiness indicator (SRI) and SPIRE. The SRI framework was introduced by the European Commission in 2018 and used to assess the preparedness of buildings for smart technologies [29]. It consists of three pillars: systems integration, real-time data, and human-centered design. The SRI framework is an extensive methodology for determining a building's readiness to exploit smart technologies. The SPIRE program, which has been created by UL Solutions (a global leader in applied safety science), is a certification initiative that centers on the key aspects of sustainability, performance, innovation, reliability, and user-friendliness in the context of smart buildings. The SPIRE technology is instrumental in promoting the development of intelligent buildings and safeguarding their advantages for proprietors and the ecosystem [30].

Data analytics plays a significant role in smart building frameworks. By collecting and analyzing data from sensors, meters, and other sources, smart buildings can derive valuable insights to improve performance and optimize operations. Data analytics techniques, including machine learning and artificial intelligence, enable advanced functionalities such as anomaly detection, fault diagnostics, and predictive analytics [20]. These insights facilitate data-driven decision making and enable proactive maintenance, resulting in improved energy efficiency and reduced operational costs. Thus, by employing data analytics, digital twin platforms have emerged as powerful tools in the context of smart building frameworks.

A digital twin is a virtual replica of a physical building that is continuously updated with real-time data from sensors and other sources. The presented frameworks emphasize different DT maturity levels of the smart building management and control strategies including reactive strategy (most buildings' status), real-time based on IoT driven, predictive strategy, and proactive strategy [31]. However, certain challenges might be faced in adopting digital twin platforms. First, the implementation of digital twin technology requires a significant investment in sensor deployment and data infrastructure. Additionally, data privacy and security concerns must be addressed when collecting and analyzing sensitive building data. Safeguarding the privacy of occupants and protecting the building's systems from cyber threats are critical considerations in the adoption of digital twin platforms [32]. Despite these challenges, the integration of digital twin (DT) platforms with data analytics holds great potential for optimizing the performance and operations of smart buildings, it is expected that digital twin platforms will play an increasingly significant role in shaping the future of smart building frameworks.

As it was presented above, various assessment schemes might be applicable to evaluate certain aspects of smart buildings. However, there is a huge challenge to combine all these aspects into one single framework.

3. Smart City

3.1. Concept of Smart City

The concept of a smart city has undergone significant development and has garnered attention in both academic and practical spheres. Over the years, various definitions and characteristics have been proposed to capture the essence of a smart city. Table 1 provides a compilation of several studies that conceptualize the smart city definition from a functional point of view. These definitions highlight the significance of human capital, social capital, information and communication technology (ICT) infrastructure, network infrastructure, physical infrastructure, wireless sensor networks (WSNs), Internet of things (IoT), technology revolution, and digital technology as integral components of smart cities [33].

Table 1. Smart city definitions proposed by different authors.

References	Smart City Definition	Indicators
Giffinger et al. [34]	"The idea of smart cities is rooted in the creation and connection of human capital, social capital, and Information and Communication Technology (ICT) infrastructure to generate a greater and more sustainable economic development and a better quality of life."	Human capital Social capital ICT
Hollands [35]	"Smart City uses the network infrastructure to improve economic and political efficiency, and to allow the social, cultural and urban development."	Network Infrastructure
González et al. [36]	"Smart City, a public administration or authority that delivers (or aims to) a set of new generation services and infrastructure, based on information and communication technologies".	ICT
British Standard Institute [33]	"The effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens".	Physical infrastructure Human capital Digital layer
Grossi and Pianezzi [37]	"Smart city or digital city is often referred to as a distributed network that consists of a large number of connected wireless sensor networks (WSNs) and IoT, and WSNs are the basic building blocks of cyber-physical systems (CPS), in particular smart cities."	Wireless sensor network (WSN) IoT
Ismagilova, E. et al. [38]	"Smart cities employ information and communication technologies to improve: the quality of life for their citizens, local economy, transport, traffic management, environment, and interaction with government."	ICT
Angeliki and Niamh [14]	"A smart city is an urban development vision that integrates information and communication technology (ICT), and IoT technology, as well as other physical devices connected to the network, to optimize the efficiency of city operations and services and connect to citizens."	ICT IoT
S Myeong et al. [39]	"A smart city is a sustainable city that solves urban problems and improves citizens' quality of life through the fourth industrial revolution technology and governance between stakeholders."	Technology revolution
M Serrano et al. [40]	"The efficient use of digital technologies to provide prioritized services and benefits to meet community goals. Without reliable measurement methods for 'smart'."	Digital technology
European Commission [41]	"A smart city is a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business."	Digital solution

In addition, the concept of a smart city emphasizes the ability to act proactively and adapt to changing circumstances [34]. It embraces advanced technologies such as artificial intelligence (AI) [42], data analytics, and automation to enable intelligent systems and services. The adaptive nature of smart city services, ICT systems, infrastructure, and buildings is crucial for providing customized, efficient, and responsive solutions to the needs of citizens [35,36].

The overarching goal of a smart city paradigm is to achieve contemporary urban governance by utilizing advanced technical instruments and cutting-edge technologies while considering ecological norms and optimizing resource consumption [40]. The integration of digital technologies, data-driven solutions, and sustainable practices remains at the core of smart city development. By leveraging these elements, smart cities strive to enhance the quality of life, improve efficiency in urban operations, and create sustainable urban environments for their residents.

The integration of smart and resilient city concepts holds great potential for enhancing resiliency in numerous ways [43]. Smart cities leverage technology to gather and analyze data, which can be utilized to identify and mitigate risks. With the large amount of data acquired by smart cities, data-driven decision making becomes possible, enabling proactive risk assessment and resource allocation. Collaboration is essential for efficient solution development and implementation among smart and resilient cities, as well as with various stakeholders such as enterprises, academics, and the general public. Furthermore, innovation is critical in embracing new technology and techniques to handle shifting difficulties [44].

3.2. Role of Digitalization in Smart Cities

Digitalization plays a pivotal role in the development of smart cities, revolutionizing urban infrastructure and services through the integration of digital technologies and connectivity. This section highlights the importance of digitalization and its influence on urban infrastructure and services in the context of smart city development [45].

The conventional city system consists of two primary layers, namely the infrastructure and services layers. The infrastructure layer pertains to the tangible constituents of the system and furnishes fundamental services that are integrated within the urban regions. It is regarded as the intermediary between the city residents and natural resources, thereby laying the groundwork for all the crucial aspects associated with the city, such as individuals, edifices, mobility, economy, governance, energy, water, and environment [46]. The services layer, commonly known as the "business layer," is constructed on a foundation of infrastructure and encompasses a range of activities that support the inhabitants of a city. These activities include municipal tasks such as water supply, waste management, environmental management, and energy distribution, among others [46]. The fundamental aspect that can successfully transform a City 1.0 into a City 2.0, commonly referred to as a smart city, is the incorporation of a data layer, also known as the digital layer.

The process of digitalization has facilitated the development of intelligent infrastructure and urban areas. The digitization of physical space and energy, information transmission, user and asset management, and business operations has been a gradual process [45]. The timely capture and sharing of information are crucial value propositions of ICT in the context of a smart city. Provided that the information is delivered promptly and with precision, urban areas have the potential to proactively address issues before they reach a critical level. According to a scholarly source, a method of conceptualizing digital infrastructure is through the utilization of various digital layers that provide support, as shown in Table 2.

Table 2. Digital layers of the smart city.

Layer	Description	Example
Urban	The stratum at which physical and digital infrastructures converge to generate intelligent edifices, smart transportation systems, smart grids, and smart waste management is referred to as the interface layer.	Smart electricity meter [46] Smart water pipes [47] Smart parking solutions [46,48] Smart waste collection logistics [49]
Sensors	This layer is made up of smart devices that measure and monitor numerous parameters of the metropolitan area and its environs.	IoT sensors [46,48] (disaster alert, air pollution, water quality chemical or radiation)
Connectivity	This process involves moving data and information from the sensor tier to storage and data aggregators for analysis.	Cloud computing [24]
Data Analytics	This pertains to the examination of data obtained from various intelligent infrastructure systems with the aim of forecasting certain occurrences.	Traffic congestion prediction [46]
Automation	The interface layer for digital enablement facilitates the automation and scalability of a vast array of devices spanning various domains and verticals.	Smart home solutions [19]

Digitalization is transforming cities by enabling the collection, analysis, and use of real-time data to improve urban services and infrastructure [50]. This includes the integration of IoT devices and sensors [24], enhanced connectivity and communication, and the development of intelligent systems and platforms. In the energy sector, digital technologies are being used to integrate renewable energy sources, demand response mechanisms, and smart metering systems. This leads to energy efficiency and sustainability. In the transportation sector, digitalization facilitates the development of intelligent traffic management systems, electric vehicle charging infrastructure, and ride-sharing platforms [51]. This promotes efficient and sustainable mobility. Digitalization is also enhancing urban services such as waste management, water management, and public safety. Smart waste management systems, digitalized water management systems, and smart security systems are all being developed to improve these services. Overall, digitalization has a positive impact on smart cities by making them more efficient [52], sustainable [14], and resilient [43].

3.3. Impact of Digitalization on Smart City Infrastructure

Digitalization has a transformative impact on various aspects of a smart city, ranging from energy management to transportation and waste management [42]. This section explores the influence of digital technologies on these domains and establishes the linkages between digitalization and the integration of smart buildings within the smart city context.

The impacts of digitalization within the smart city realm are substantial and extensive. The integration of digital technologies and data-driven processes, commonly referred to as digitalization, has been observed to yield numerous benefits and transformations in smart cities. The visual representation depicted in Figure 1 illustrates the primary effects of digitalization on the smart city sector.

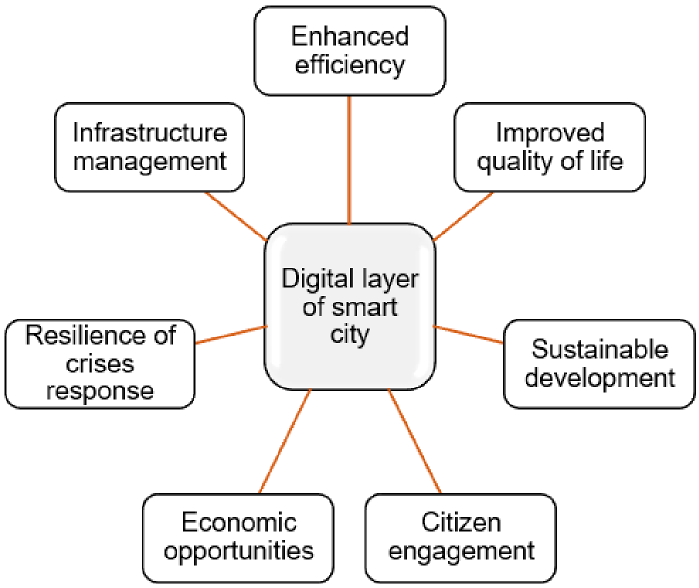

Figure 1. The influence of the digital layer on smart city transformation.

In the process of digitalization, data is utilized to improve decision-making processes, optimize resource allocation, and improve the delivery of services in various sectors, including transportation, energy, waste management, and public safety [53]. The use of IoT, AI, and data analytics improves resource optimization, emission reduction, and environmental management in urban areas [54].

Energy management is significantly affected by digitalization. Digital technologies enable the deployment of smart grids, which integrate renewable energy sources, advanced metering systems, and intelligent control mechanisms. This integration optimizes energy distribution, facilitates demand response programs, and promotes energy efficiency in smart cities [8]. The availability of real-time energy data and analytics allows for informed decision making and effective energy management strategies [53,55]. Transportation is another area where digitalization plays a critical role. Intelligent transportation systems leverage digital technologies, such as traffic sensors, real-time data analytics, and smart mobility platforms, to optimize traffic flow, reduce congestion, and enhance transportation efficiency. Digitalization also facilitates the integration of electric vehicles, car-sharing services, and intelligent parking systems, promoting sustainable mobility options within smart cities [10,56]. Waste management is significantly influenced by digitalization as well. Smart waste management systems leverage sensors, IoT devices, and data analytics to monitor waste levels, optimize collection routes, and improve recycling processes. Real-time data enables efficient resource allocation and waste reduction strategies, leading to a more sustainable waste management approach [57].

Furthermore, digitalization establishes critical linkages between digital technologies and the integration of smart buildings within the smart city domain. Smart buildings leverage digital technologies, such as building automation systems, sensor networks, and data analytics, to optimize energy consumption [19], enhance occupant comfort, and improve operational efficiency. The integration of these digital systems within smart buildings enables effective energy management, predictive maintenance, and personalized user experiences [13]. Digitalization provides the necessary infrastructure and connectivity for smart buildings to interact with the broader smart city ecosystem, enabling data exchange, interoperability, and resource optimization across various domains.

The impact of digitalization on smart city domains is a complex and interconnected phenomenon. It underscores the transformative potential of digital technologies in enhancing sustainability, efficiency, resilience, and quality of life within urban environments. Moreover, the linkages between digital technologies and smart building integration highlight the synergies and interdependencies between these two essential components of a smart city.

4. Smart Building Integration into Smart City

The integration of smart buildings into smart cities is a critical aspect of creating sustainable, efficient, and resilient urban environments. This section presents a conceptual framework for the integration of smart buildings into smart cities considering a city as a technological system. It highlights the importance of integration for achieving sustainability, resource optimization, resilience, and enhanced urban living.

4.1. Conceptual Framework of Smart Building Integration into a Smart City

The integration of smart buildings into smart cities involves the seamless incorporation of individual smart buildings into the broader urban infrastructure and ecosystem. A conceptual framework for smart building integration can be established based on three key dimensions Figure 2 physical integration, data integration, and functional integration.

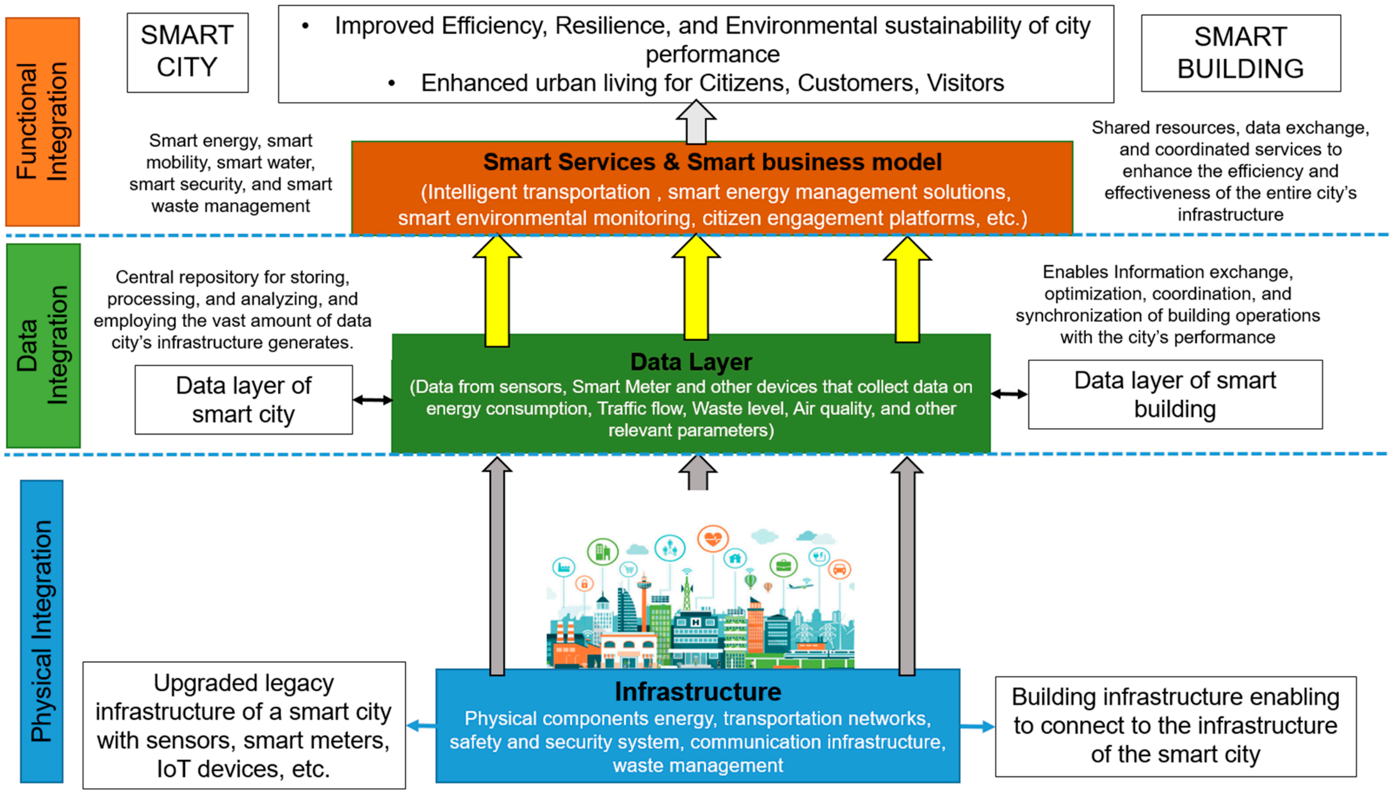

Figure 2. Conceptual framework of smart building integration into a smart city.

The physical link and interaction between smart buildings and the surrounding urban environment is referred to as physical integration. It entails integrating building systems with city infrastructure, such as power grids, transportation networks, and water supply systems. Physical integration enables resource sharing, coordinated operations, and optimized utilization of infrastructure resources [20].

Data integration involves the collection, sharing, and analysis of data from smart buildings and other urban systems. It requires the development of interoperable data platforms and protocols to enable seamless data exchange and integration. Data integration allows for comprehensive monitoring, analysis, and decision making at the city level, leading to improved resource management and urban planning [58].

Functional integration focuses on the collaborative operation and coordination between smart buildings and other urban entities. It involves the alignment of building operations with city-level objectives, such as energy efficiency, environmental sustainability, and citizen well-being. Functional integration enables collective optimization, where smart buildings work together as a system to achieve shared goals, such as load balancing, demand response, and environmental impact reduction [11,59].

4.2. Importance of Integration for Efficiency, Resilience, and Sustainability of City Performance

The integration of smart buildings into smart cities is crucial for achieving efficiency, resilience, and sustainability in city performance.

Efficiency refers to the use of technology and data-driven solutions to improve the performance and quality of municipal services while consuming fewer resources and spending less money. By integrating energy-efficient systems, smart meters, and advanced control algorithms, smart buildings contribute to overall energy savings and reduced environmental impact [60]. The integration allows for coordinated energy management strategies, such as load shifting, peak shaving, and renewable energy utilization [61], leading to enhanced energy efficiency and reduced greenhouse gas emissions [62].

Furthermore, integration enables resource optimization by leveraging the interconnectedness of smart buildings with other urban systems. The integration of smart buildings with smart grids facilitates demand response initiatives, whereby buildings adapt their energy usage in response to grid conditions and pricing cues [17]. This collaboration between buildings and the grid leads to more efficient energy distribution, reduced strain on the grid, and enhanced overall system reliability.

Within the framework of integrating the smart building into a smart city, environmental sustainability is another important metric in this scenario. It involves the implementation of an energy-efficient system such as renewable energy, advanced control algorithms, ICT, and smart meters to curtail energy usage and mitigate environmental impact [63]. Integration also facilitates the optimization of water management and waste management within smart cities. Smart buildings can incorporate water-efficient technologies, such as smart irrigation [64], rainwater harvesting systems, and greywater recycling [65] contributing to water conservation at the city level [49]. In waste management, integration enables real-time monitoring of waste generation, optimized waste collection routes [57], and improved recycling practices, leading to efficient waste management and reduced environmental impact [66].

In contrast, resilience usually refers to the capacity of a system to withstand and recover from unexpected disturbances and pressures while preserving its operational and adaptive capabilities. The concept of resilience in the realm of smart cities and buildings pertains to the development of structures and urban infrastructures that possess the ability to forecast, adapt, adjust to, and recuperate from disruptive occurrences [67]. The integration of smart buildings into smart cities in a resilient manner involves implementing strategies to strengthen infrastructure durability, enhance emergency response mechanisms, and foster community resilience, as indicated in [43]. The integration of resilient characteristics in smart buildings can effectively enhance the overall resilience of urban areas by minimizing the adverse effects of various disruptions, including but not limited to natural calamities, climate change, and system breakdowns. The integration in question allows for the prompt monitoring of multiple parameters in real time, thereby enabling swift responses and adaptable measures in emergency situations [68].

To improve efficiency, resilience, and sustainability in city performance, smart buildings need to be integrated into smart cities. The connectivity of smart buildings with other urban systems allows for coordinated energy management techniques, which in turn leads to increased energy efficiency, decreased greenhouse gas emissions, and resource optimization. Energy conservation is achieved through the incorporation of water-efficient technologies and optimized waste management practices, while environmental impact is lessened by reducing energy consumption and using renewable energy sources and cutting-edge control algorithms and smart meters. Finally, smart cities aim to improve infrastructure longevity, and emergency response mechanisms by integrating security systems, and community resilience through the incorporation of smart buildings.

4.3. Enhanced Urban Living through Smart Services

The integration of smart buildings into smart cities ultimately aims to enhance urban living experiences. By integrating technologies such as Internet of things (IoT) devices, data analytics, and personalized services, smart buildings can provide tailored and responsive experiences to occupants [59]. This includes adaptive lighting, personalized comfort settings, and optimized indoor environmental quality [27]. Integration also enables smart building services to extend beyond individual buildings, such as smart parking, shared mobility, and intelligent community services.

The implementation of ubiquitous computing technology relies on the integration and organized interconnection of smart service systems that oversee the administration of edifices and urban areas [20,40], as well as their engagement with users. The initial phase involved establishing and implementing the IoT [3], which involved linking household appliances to the network and facilitating communication with the building or municipal infrastructure [2], as well as with the user. Subsequently, a methodical approach involves the installation of diverse sensors and devices within buildings [59]. This, in conjunction with the IoT, facilitates the gathering, transmission, analysis, and reaction to the accumulated data and additional engagement with occupants.

The optimization of city infrastructure systems, including energy, water, and traffic, is a significant advantage of urban intelligent systems and smart building networking. Until recently, the capabilities of integration and system interaction have been restricted to data transfer technologies. However, the emergence of the 5G network has altered this landscape, as its data transfer rate is now sufficient to support the implementation of autonomous vehicle transport and other advanced applications. It is anticipated that the current speed standard will be augmented in the near future, thereby facilitating additional advancement and interactivity of said systems.

It is imperative to acknowledge the wider societal and technological ramifications of IoT advancement, while also prioritizing the interdependent connection between the intelligent frameworks of smart cities and smart buildings. The investigation of these effects is currently underway in numerous fields. However, it is important to acknowledge that the optimal implementation of such projects requires the synergy of urban systems, including infrastructure, transportation, and administration.

5. Factors Affecting Smart Building Integration into Smart City

This part of the paper synthesizes the findings and provides a comprehensive analysis of the factors influencing smart building integration into smart cities taking into account the technological aspects of the city. Given the multitude of factors identified, the study conducted a synthesis to organize and categorize them based on thematic areas. This categorization led to the identification of five main infrastructure areas: smart energy, smart mobility, smart water, smart security systems, and smart waste management. Each of these thematic areas is described in detail in the subsequent subsections. By categorizing the factors according to their respective infrastructure, it aimed to provide a comprehensive understanding of the different aspects that contribute to the integration of smart buildings into smart cities. The detailed descriptions of each thematic area enabled a deeper exploration and analysis of the factors involved in each domain.

5.1. Factors Related to Smart Energy

The smart energy services of a smart building are essential for all aspects of both smart buildings and shaping the overall performance and sustainability of the smart city, from powering homes and businesses to providing transportation and lighting. For example, the integration of energy storage systems such as batteries of advanced storage technologies in smart buildings enhances energy management capabilities [69], which enables the capture and utilization of surplus energy generated by renewable sources [61], allowing for better demand response management, load balancing, and peak shaving. Smart buildings serve as key nodes in the integration of smart grids, enabling bidirectional communication and dynamic energy management [8]. Therefore, the impact of smart energy solutions in smart buildings is substantial in smart cities as well. Through renewable energy adoption, energy efficiency measures, energy storage, sharing thermal energy, and integration with smart grids, smart buildings contribute to the overall sustainability, resilience, and efficiency of smart cities. By embracing these technologies and approaches, smart cities can achieve a more sustainable, clean, and reliable energy future while optimizing resource utilization and reducing carbon emissions Table 3 provides specifics on the smart building's energy services and how they work.

Table 3. Factors enabling smart energy services.

Factors	Description	References
Electrical energy storage (battery)	Technology helps to stabilize power output and energy demand by storing excess or unused electrical energy and providing it to the grid or customers as needed.	[61,69–72]
Sharing electrical energy storage	A technology concept of utilizing a centralized energy storage system that can be accessed and utilized by multiple buildings within a community or network.	[61,69,70,73]
Ability to work off-grid (renewable energy source: solar wind)	Refers to their capability to operate independently from the central power grid, utilizing self-generated or stored energy sources.	[62,71,74]
Energy usage monitoring and control, demand-side management	Implementation of systems and technologies to track, analyze, and regulate energy consumption within the building.	[71,75,76]
Smart heating, cooling, and hot water preparation	Refers to the smart distribution and utilization of heating and cooling resources among multiple building units or spaces.	[77,78]
Thermal energy storage	Implementation of systems and technologies that enable the efficient storage, management, and utilization of thermal energy within building envelopes or components.	[69,72,75]
Sharing thermal energy storage	Thermal energy storage systems in a cluster of buildings optimize thermal energy management and efficiency. Thermal energy is stored in pre-heated water tanks. During periods of low demand and low electrical energy cost and then used during periods of high-temperature regulation demand.	[69]

5.2. *Factors Related to Smart Mobility*

Mobility is another critical aspect in the context of smart buildings and smart cities, it plays a crucial role in enhancing transportation efficiency, reducing congestion, and improving the overall quality of life. By examining the importance of the factors presented in Table 4. and their contribution to the performance of the city, it could be stated that electric vehicles (EVs) and EV charging points contribute to reducing dependence on fossil fuels and decreasing carbon emissions [79]. Carpooling and ride-sharing services enable multiple individuals to share a single vehicle and reduce the number of cars, these services can be facilitated through digital platforms that connect passengers and drivers, optimizing routes and enhancing transportation efficiency [51]. Modern parking solutions such as shared parking and online video surveillance normally comprise inter alia network of sensors, real-time data, and a global positioning system to provide information on parking availability, and guide drivers to vacant parking spaces efficiently [80].

Table 4. Factors enabling smart mobility services.

Factors	Description	References
Smart EV charging	A technology of integration of smart charging solutions for electric vehicles that optimize energy consumption, adapt charging strategies, and provide additional benefits for consumers and the overall energy system.	[9,72,79,81]
Carpooling–ride sharing	Refers to the practice of sharing rides among individuals working or residing in the same building or complex.	[9,56,82]
Smart parking management system (E-parking)	Sensors, IoT devices, and real-time data to provide management and visibility into parking space.	[9,80,83,84]
Sharing parking space	Refers to the practice of allowing multiple individuals or organizations to utilize the same parking area or facility.	[9,80,83,84]
Online video surveillance	CCTV cameras with implemented technology use various techniques and algorithms to monitor and analyze video footage in real time, enabling smart systems to detect and respond to mobility-related events.	[9,72,85]
Last mile driving	It is a transportation solution to address the final journey from a transportation hub to the final destination point by using self-driving vehicles.	[82]

Therefore, incorporation of these smart services in smart buildings contributes to creating smart mobility strategies, and more sustainable and efficient transportation systems in cities through improved traffic flow, reduced congestion, and enhanced overall mobility experience for residents and visitors.

5.3. Factors Related to Smart Water

Smart water solutions play a crucial role in enhancing the sustainability and efficiency of smart buildings and their impact extends to the overall performance of smart cities. Implementing smart water solutions in the smart building shown in Table 5., such as water conservation measures, real-time monitoring, leak detection systems, and smart irrigation contribute to optimized water usage, reduced wastage, and ensured water availability for both residents and businesses. They also support sustainable development by mitigating the strain on water resources, enhancing resilience to water-related challenges, and promoting more efficient use of water in buildings and urban areas. By integrating these smart water technologies, cities can move towards a more sustainable and water-resilient future.

Table 5. Factors enabling smart water services.

Factors	Description	References
Smart water mixtures	Integration of technology and systems to monitor, control, and optimize water usage within building infrastructures, and conservation	[64,81]
Smart water monitoring and shutoff (leak detection and prevention)	Smart water management systems detect water leaks and alert building operators	[64,81,86]

Table 5. *Cont.*

Factors	Description	References
Smart water irrigation system	An automated irrigation control based on real-time soil moisture, weather, and plant water requirements from soil sensors	[64,81,87]
Smart water meter	An advanced metering infrastructure for online water consumption monitoring	[64,81]
Greywater recycling	A sustainable solution for repurposing water that is typically discharged from showers, bathtubs, washbasins, laundry, and swimming pools	[64,72]
Rainwater collection (harvesting) and reuse	A sustainable method that collects and uses rainwater in the building's infrastructure to conserve water and prevent flooding	[64,72]

5.4. Factors Related to Smart Security System

A smart security system is a top-priority integral component for a smart building and a city [88]. Smart buildings are tapping into the IoT to enable more applications to connect, and that includes physical security solutions presented in Table 6, such as video surveillance, fire detection, disaster event communication, and smart security lights. In a smart building, video surveillance solutions can identify potential risks, such as a person of interest in a parking lot [89], track that person, and report findings back to a security team, all in real time. These technologies enable better monitoring, detection, and response to fire [90], resulting in improved safety measures and performance within a city, enabling early detection, enhancing incident command centers, improving fire suppression methods, and providing situational awareness to firefighters. All these solutions have a significant impact on a city's performance by increasing safety, minimizing damage, and facilitating efficient emergency response. In the same scenario, IoT devices are utilized to collect data and aid in the identification of alarms following disasters as well as the localization of injured persons [90].

Table 6. Factors enabling smart security services.

Factors	Description	References
Smart monitoring and data analytics of the surrounding environment	CCTV cameras and advanced algorithms enable real-time video analytics for face recognition, people counting, attendance management, and emotion analysis.	[72,81,85,89,91]
Smart fire management	An application of IoT technologies and advanced systems to enhance fire safety and responses.	[72,81,90]
Disaster event communication management	IoT, cloud computing, video surveillance, and communication networks were used to detect and respond to disasters.	[92,93]
Smart security lightning	A Lightning system uses advanced technologies like IoT and intelligent control for perimeter security, enhancing smart building security infrastructure and occupant safety.	[72,81]
Integrated sensors solutions	IoT sensors integrate various functionalities into a single device, offering a condensed and all-encompassing approach to monitoring environmental factors simultaneously. This integration enables the measurement of temperature, humidity, and air quality in a single unit.	[65,94,95]

5.5. Factors Related to Smart Waste Management

Waste management often entails waste monitoring, collection, transportation, processing, recycling, and disposal. Smart waste management systems aid in waste reduction by categorizing garbage at the source and developing ways for proper waste disposal. Such systems could be used to recycle garbage and establish closed-loop economies. Their key advantages are improved garbage collection, pick up, separation, reuse, and recycling efficiency. One of the most significant inefficiencies in trash management is the inability to predict when waste will be collected; trucks are frequently dispatched to collect rubbish when bins are not full. Sensors, connection, and the Internet of things (IoT) provide strategies to avoid additional expenses associated with such inefficiencies, where a smart bin and automated waste collection smart waste management systems monitor the movement of various types of garbage, and technology can be used to better understand and manage the flow of waste from source to disposal [6]. Table 7 provides specifics on the smart waste solutions which play an important part in this case.

Table 7. Factors enabling smart waste management services.

Factors	Description	References
Smart waste containers	A waste management solution that leverages technology such as AI, data-driven approach, and IoT sensors to improve waste collection, and optimize waste management processes.	[57,66,96]
Automated and robotic waste collection	A gravity and full vacuum system collects garbage and transports it through underground pipes to a nearby station for sorting and compacting, crucial for recycling materials.	[97,98]

6. Case Studies of Successful Smart Buildings Integration into Smart Cities

6.1. Introduction to Case Studies

Five case studies from different geographical locations were selected to highlight successful smart building projects that demonstrate fulfilled integration requirements based on the smart infrastructure development of the city.

The Edge is a highly intelligent and ecologically efficient building located in the Netherlands, in Amsterdam's Zuidas business sector. It received a 98.4% rating on the BREEAM scale in 2015 [99], the highest ever recorded. Deloitte occupies the 40,000-square-foot office building. Advanced sensor systems, lighting control systems, rainwater reuse, smart HVAC systems, thermal energy storage systems, and a central building management system (BMS) for real-time monitoring are all part of the building's design. The Edge combines several technologies, such as IoT connection, a cloud-based analytics platform, intelligent meters, and real-time energy monitoring. It also emphasizes the significance of ongoing feedback and occupant participation to increase comfort and satisfaction. By partnering with local community partners, the building's design also promotes environmental measures [100,101].

One Angel Square, a Manchester-based smart building in the UK, aims to create a sustainable and energy-efficient working environment for its occupants [102]. The building incorporates intelligent lighting systems, a combined heat and power plant, and heat recovery systems for heating and cooling [103]. It also utilizes building automation, control systems, energy management software, and renewable energy sources like rooftop solar panels. The building's design incorporates social and stakeholder engagement strategies, involving occupants and local community stakeholders. One Angel Square has achieved BREEAM outstanding certification for sustainability [104], reducing energy consumption by over 50% compared to previous office buildings. This achievement showcases the successful integration of smart technologies, energy-efficient systems, and stakeholder engagement in creating a highly sustainable and environmentally friendly office building [105].

The National University of Singapore (NUS) was designated as the Green Mark Platinum Champion for its outstanding role in sustainable development, successfully obtaining a 50 Green Mark certificate and being awarded Zero Energy winner for its campuses [106]. The bestowed recognition is conferred upon structures that have been certified for their achievement in attaining either zero energy consumption or exceptionally low energy consumption levels. The university has set a goal of achieving carbon neutrality on its campus by the year 2030 [107]. In addition, it has implemented a smart building integration program to improve energy efficiency, occupant comfort, and operational efficiency. The program includes smart lighting systems with occupancy and daylight sensors, personalized HVAC systems, and an integrated building management system (iBMS). Real-time energy monitoring and analytics are employed to provide insights into energy consumption patterns and facilitate targeted energy-saving strategies. This has led to significant reductions in energy consumption and carbon emissions, improved occupant comfort and productivity, and the successful implementation of demand response strategies for peak load management [108].

Ongos Valley, a smart building development in Windhoek, Namibia, focuses on sustainable design and advanced technologies to create an environmentally friendly community. By integrating renewable energy sources and implementing efficient water management practices, the project reduces dependence on traditional energy sources and achieves a lower carbon footprint [109]. Ongos Valley prioritizes residents' quality of life and well-being, promoting a comfortable and sustainable living environment [110]. The project emphasizes collaborative partnerships with local stakeholders, fostering a collective approach to project success and long-term sustainability [111].

Reliance MET City, a large-scale development near Gurgaon, India, focuses on sustainable urban living by integrating smart building systems and reducing energy consumption and carbon emissions. It prioritizes waste management and recycling practices to promote environmental sustainability [112]. MET City aims to improve the quality of life and livability of residents, offering a comfortable and advanced urban environment [113]. Reliance MET City, a subsidiary of Reliance Industries Limited, is developing state-of-the-art infrastructure and amenities, offering a 'walk to work' advantage to residents. With rapid growth, the city has become a hub for economic development, attracting companies and residential customers [114].

6.2. Case Study Analysis and Results

Table 8 presents a summary of the above-mentioned case studies analysis showcasing successful smart building integration into smart cities. It provides information about key integration factors addressed in the previous chapter of this paper.

The graphical representation of the technological factors enabling smart services implemented in each case study is presented in Figure 3. All of the indicators from the list of 26 were proven. In the energy sector, European cities, particularly Amsterdam, demonstrate a strong focus on sustainability and resilience [115], which involves the implementation of an energy-efficient system and the ability to adapt to disruptive occurrences, such as renewable energy, energy storage advanced control algorithms, and ICT to curtail energy usage and mitigate environmental impact. They lead in energy storage and off-grid potential, indicating a commitment to integrating renewable energy sources and enhancing energy management. According to Figure 3, The Edge in Amsterdam has 5 out of 7 services integrated to address their smart city goals in the context of energy storage and implementing renewable energy sources. On the other hand, Asian cities prioritize smart EV infrastructure, reflecting their goals of promoting electric transportation and addressing concerns related to rapid motorization. This regional variation highlights the different approaches taken toward energy transition and sustainability [116]. Two Asian projects, i.e., Reliance MET, Gurgaon, India and (NUS) smart buildings, Singapore, have energy services 4 and 3 out of 7, respectively.

When it comes to mobility, all analyzed case studies are developed to promote smart and sustainable mobility. European cities stand out in promoting shared mobility services and reducing private car usage [117]. Both The Edge in Amsterdam and One Angle Square in the UK integrated 5 mobility services out of 6. This emphasizes their commitment to sustainable transportation solutions, reducing traffic congestion, and enhancing last-mile connectivity. Asian cities (NUS, Singapore—5 out of 6 services; Reliance MET, Gurgaon, India—4 out of 6 services) address the challenges of rapid urbanization by placing a stronger emphasis on promoting sharing mobility, video surveillance, and parking management, indicating concerns related to motorization and the need for efficient parking solutions [116]. African cities lag behind in smart mobility, likely due to cost constraints and infrastructure challenges they face in implementing advanced mobility systems.

Table 8. Case studies of successful smart building integration into a smart city.

Domains		Factors Related to the Smart Services	The Edge Amsterdam, the Netherlands	One Angel Square Manchester, UK	(NUS) Smart Buildings, Singapore	Ongos Valley, Windhoek, Namibia	Reliance MET City Gurgaon, India
ENERGY	1	Electrical energy storage (batteries)	✓	✓	✓	✓	
	2	Sharing electrical energy storage				✓	✓
	3	Ability to work off-grid (renewable energy sources wind–solar)	✓		✓		✓
	4	Energy usage monitoring and control, demand-side management	✓	✓		✓	✓
	5	Smart heating, cooling, and hot water preparation	✓		✓		✓
	6	Thermal energy storage	✓			✓	
	7	Sharing thermal energy storage				✓	
	Total ENERGY		**5 out of 7**	**3 out of 7**	**3 out of 7**	**5 out of 7**	**4 out of 7**
MOBILITY	1	Smart EV charging	✓	✓	✓		✓
	2	Carpooling–ride sharing	✓	✓	✓	✓	✓
	3	Smart parking management system (e-parking)	✓	✓	✓	✓	✓
	4	Sharing parking space	✓		✓		
	5	Online video surveillance			✓	✓	
	6	Last mile driving	✓	✓		✓	✓
	Total MOBILITY		**5 out of 6**	**4 out of 6**	**5 out of 6**	**4 out of 6**	**4 out of 6**
WATER	1	Smart water mixtures	✓		✓	✓	✓
	2	Smart water monitoring and shutoff	✓	✓	✓	✓	✓
	3	Smart water irrigation system			✓		
	4	Smart water meter	✓	✓	✓	✓	✓
	5	Greywater recycling	✓				✓
	6	Rainwater collection (harvesting) and reuse	✓			✓	
	Total WATER		**5 out of 6**	**2 out of 6**	**4 out of 6**	**4 out of 6**	**4 out of 6**
WASTE	1	Smart waste containers	✓	✓	✓	✓	✓
	2	Automated and robotic waste collection			✓	✓	✓
	Total WASTE		**1 out of 2**	**1 out of 2**	**2 out of 2**	**2 out of 2**	**2 out of 2**

Table 8. *Cont.*

Domains		Factors Related to the Smart Services	The Edge Amsterdam, the Netherlands	One Angel Square Manchester, UK	(NUS) Smart Buildings, Singapore	Ongos Valley, Windhoek, Namibia	Reliance MET City Gurgaon, India
SECURITY	1	Monitoring and analysis devices: face detection	✓	✓	✓	✓	✓
	2	Monitoring and analysis devices: car plate detection	✓	✓	✓	✓	✓
	3	Smart fire management	✓	✓	✓	✓	✓
	4	Disaster event communication management	✓			✓	
	5	Security smart lights	✓	✓	✓	✓	✓
		Total SECURITY	**5 out of 5**	**4 out of 5**	**4 out of 5**	**5 out of 5**	**4 out of 5**
		TOTAL	**21**	**14**	**18**	**20**	**18**

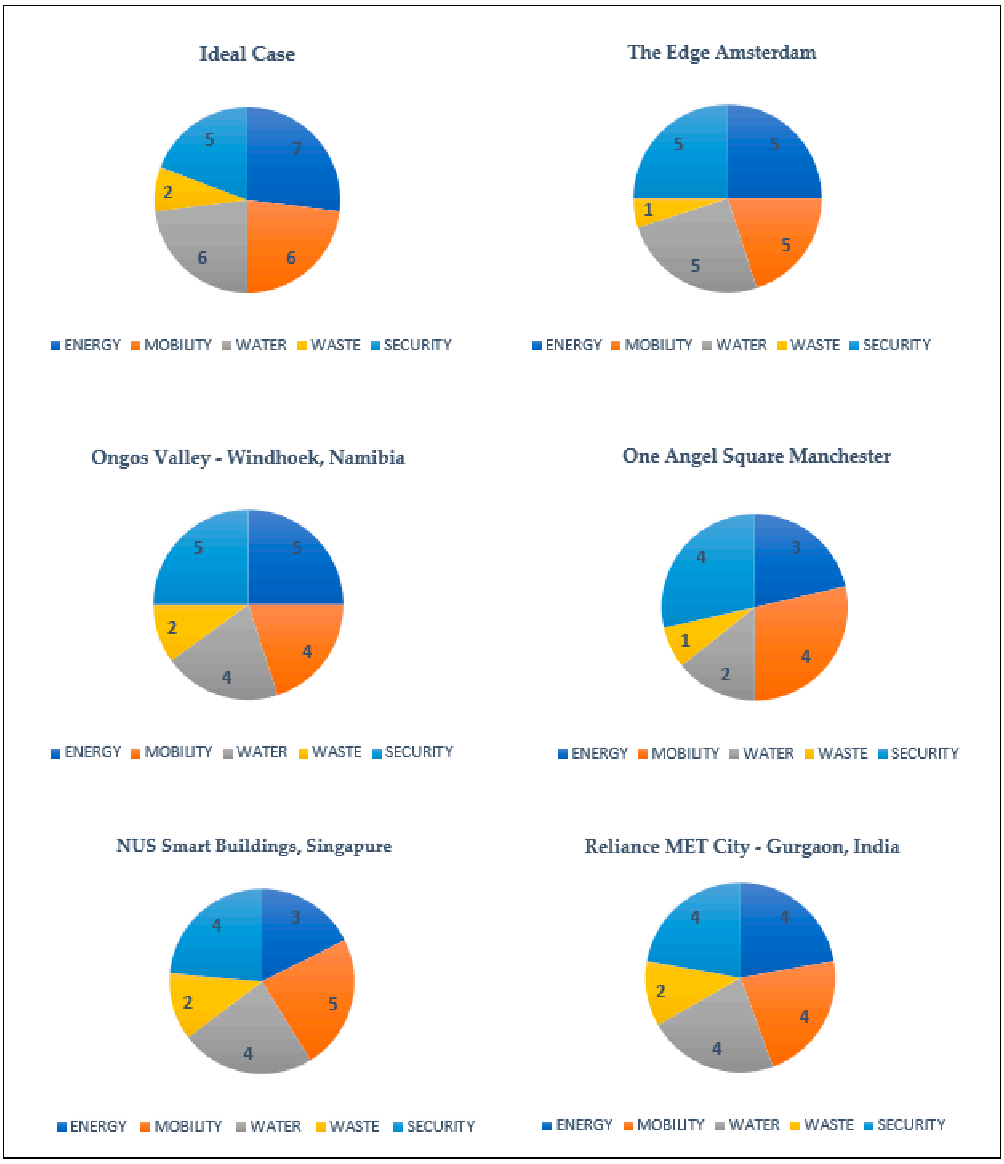

Figure 3. Case studies: key factors related to smart services of different smart cities domains.

In water and waste management, regional patterns are evident. Water conservation and recycling initiatives are more prevalent in regions with water scarcity, such as in Africa and India (4 out of 6 water services). Singapore stands out for its comprehensive smart water management initiatives, emphasizing the importance of efficient water use in a water-stressed environment [118]. In waste management, European cities lead in automation, sensors, and data analytics, reflecting their focus on achieving greater efficiency and sustainability goals [49]. Other regions primarily utilize basic smart bins due to a lack of adequate infrastructure, suggesting the potential for further development and utilization of waste data.

The security domain demonstrates high development status within the selected case studies: The Edge, Amsterdam and Ongos Valley, Windhoek have security as a first priority (5 out of 5) while the rest of the projects have implemented 4 smart services out of 5. This shows that the enhanced smart city initiatives provide the overall measurements to increase not only the efficiency and sustainability but the resilience of smart city performance, including safety and security services for their inhabitants as well.

Based on the analysis of case studies, several recommendations can be made to enhance the technological aspects of smart city initiatives. Firstly, there is a need to expand renewable energy and storage solutions to increase self-sufficiency and resilience against grid disruptions. Technologies such as vehicle-to-grid systems and energy trading platforms can facilitate the integration of mobility and energy sectors. Furthermore, scaling sustainable mobility options like shared vehicles, e-buses, and demand-responsive transit can improve convenience and reduce congestion. Integration of payment and scheduling systems across different modes of transport will enhance usability. Additionally, expanding environmental monitoring by leveraging low-cost sensors can provide hyperlocal data on air and water quality, which can inform evidence-based policies. It is also essential to invest in cybersecurity measures and develop robust data governance frameworks to address privacy concerns and build public trust. Finally, pursuing regional partnerships and knowledge exchange with other cities can facilitate the replication of successful use cases and accelerate smart city development. Collaborative efforts and a shared vision across sectors and stakeholders are essential for the realization of integrated, inclusive, and sustainable smart cities. By learning from best practices and focusing on local priorities, cities can drive the realization of technologically optimized urban living in a way that best serves their communities.

7. Discussion

In this chapter, the identified factors, their interrelationships, and their implications for successful integration are discussed. Additionally, common challenges, limitations, and areas for further research are identified.

The study reveals that 26 key factors play a crucial role in the integration of smart buildings into smart cities. These factors include smart energy, smart mobility, smart water, smart security systems, and smart waste management infrastructure domain. Each of these thematic areas has unique requirements, frameworks, and technologies that contribute to the overall integration process. Despite the progress made in smart building integration into smart cities, some common challenges need to be addressed. These include data interoperability, privacy and security concerns, regulatory barriers, technological complexities, and the need for scalable and cost-effective solutions.

In the context of smart energy integration, the adoption of energy-efficient systems, renewable energy integration, and demand-side management are essential. However, challenges such as the coordination of diverse energy resources and the integration of energy storage systems need to be addressed to ensure seamless integration and maximize energy optimization.

Smart mobility integration requires the integration of smart transportation systems, electric vehicles, and intelligent traffic management. This integration enables congestion reduction, emissions reduction, and enhanced mobility. Nevertheless, challenges related to data management, interoperability, and infrastructure development must be overcome to fully realize the benefits of smart mobility integration.

The integration of smart water management solutions enables water conservation and reuse, real-time leak detection, and quality monitoring. It contributes to efficiency and sustainability in water management. However, challenges related to data privacy, system interoperability, and infrastructure investment need to be addressed for successful smart water integration.

Smart security systems, including intelligent surveillance, access control, and emergency response systems, enhance safety, crime prevention, and resilience in smart buildings and cities. However, privacy concerns, cybersecurity threats, and the integration of diverse security systems pose challenges to effective integration.

The application of IoT-based waste monitoring, recycling, and waste-to-energy systems in smart waste management contributes to efficient waste management and supports circular economy goals. E-waste management practices, on the other hand, should align with the broader goals of sustainability and environmental preservation within smart cities. This can involve the use of IoT techniques such as radio frequency (RFID) and sensor technology to track and manage e-waste throughout its lifecycle [66]. However, challenges related to data management, infrastructure, and public engagement need to be addressed to achieve effective integration.

The integration of smart buildings into smart cities raises concerns and potential risks. Data protection becomes increasingly important as smart buildings generate and gather massive volumes of personal and sensitive data, raising the danger of data breaches and illegal access. Another concern is over surveillance, as continual monitoring via integrated sensors and surveillance technology might intrude on privacy and personal freedom. Furthermore, smart buildings may unintentionally contribute to inequality by raising costs and posing accessibility issues for low-income populations. Finally, an overreliance on technology in smart buildings may result in interruptions and dependencies that disrupt vital activities. To address these threats, comprehensive approaches such as strong data protection rules, cybersecurity safeguards, and fair access programs must be implemented, all while protecting privacy rights and fostering openness.

The scope of this study is related to the technological aspects of smart buildings integration into smart cities, and this is the major limitation. Additionally, a variety of other aspects might be further investigated in the future such as, for example, the impact of smart building integration on the social, economic, and environmental aspects of smart cities. The human factor (residents or building owners) is one such important factor that needs to be carefully analyzed and assessed. The evaluation of long-term sustainability, user acceptance, and the cost-effectiveness of integrated solutions is essential for the successful implementation of smart building integration projects. Adopting a human-centric approach that prioritizes equity and accessibility in service delivery is also crucial. Citizen feedback loops through social media, mobile apps, and the Internet of things can enable co-creation and ensure that smart city initiatives address the needs of all residents. Challenges that arise from technological advances such as electromagnetic radiation of smart buildings and smart cities, e-waste, a plethora of under-sea cables, etc., and their impact on the integration of smart buildings into a smart city have to be analyzed and taken into account by decision makers.

In summary, advanced digital technologies enable the integration of smart buildings into smart cities and new smart services provide enormous benefits to the cities and their inhabitants. At the same time, potential threads caused by certain technologies need to be discussed and leveraged in each infrastructure area; thus, additional measures should be implemented to minimize the negative effects correspondingly. These decisions are within the responsibility limits of the city planners and smart city strategy development authorities who pave the way for new technologies selection and implementation to integrate smart buildings into a particular smart city. Thus, further research is required to develop standardized frameworks, guidelines, and best practices for successful integration. The next stage to continue this research is to present the smart building integration into the smart city evaluation framework by considering the identified technological factors and their impact on the efficiency, resilience, and environmental sustainability of the city's performance.

8. Conclusions

The presented study researched the key factors affecting the smart building integration into the smart city considering technological aspects. The established conceptual framework revealed three key dimensions of smart building integration into a smart city: physical, data, and functional. The research revealed that the successful integration of smart buildings into smart cities requires attention to multiple factors. Through a comprehensive review of the relevant literature and case studies research, 26 factors influencing integration in five infrastructure areas, namely smart energy, smart mobility, smart water, smart security systems, and smart waste management, were identified and discussed. The findings have important implications for policymakers, urban planners, and stakeholders involved in smart city development.

In the area of smart energy, the adoption of energy-efficient systems, renewable energy integration, and demand-side management are critical for achieving energy optimization and sustainability. Policymakers and urban planners should prioritize the development of supportive regulations, incentives, and infrastructure to encourage the implementation of these technologies.

Smart mobility integration plays a vital role in enhancing transportation efficiency and reducing congestion and CO_2 emissions. Policymakers and urban planners should focus on the integration of smart transportation systems, the promotion of electric vehicles, and the implementation of intelligent traffic management strategies. Investments in infrastructure, such as charging stations and smart traffic control systems, are necessary to support the widespread adoption of smart mobility solutions.

Smart water management is essential for achieving sustainable water use in smart cities. Policymakers and urban planners should emphasize the integration of smart water monitoring systems, leak detection technologies, and water conservation practices. Investments in infrastructure and the development of data-sharing mechanisms can enable efficient water management and ensure the long-term sustainability of water resources.

The integration of smart security systems is crucial for ensuring the safety and resilience of smart buildings and cities. Policymakers and stakeholders should prioritize the implementation of intelligent surveillance, access control, and emergency response systems. It is also important to address privacy and cybersecurity concerns through robust data protection measures and secure communication protocols.

Smart waste management integration contributes to efficient waste disposal, recycling, and resource recovery. Policymakers and urban planners should promote the adoption of IoT-based waste monitoring systems, encourage recycling initiatives, and explore waste-to-energy solutions. Public awareness campaigns and incentives can encourage active participation and support the transition toward a circular economy.

The successful integration of smart buildings into smart cities and the identification of the sets of integrated smart building services require a thorough and synchronized strategy. Effective addressing of the challenges and capitalization on the opportunities presented by smart technologies necessitates collaboration among policymakers, urban planners, real estate professionals, technology providers, and other associated stakeholders.

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