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Article

Empowering smart cities: The role of intelligent building solutions in urban development

Fateme Vafaei, Javad Majrouhi Sardroud*, Mostafa Ghazimoradi

Department of Construction Management, Faculty of Civil and Earth Resource Engineering, Central Tehran Branch, Islamic Azad University, Tehran 1955847781, Iran

*** Corresponding author:** Javad Majrouhi Sardroud, Ja.Majrouhi@iau.ac.ir

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Abstract: Integrating intelligence into building structures offers numerous benefits for smart cities. This research focuses on the significance of smart buildings within city environments settings, providing valuable insights into the seven domains that significantly impact smart cities. It emphasizes the development of smart buildings that positively influence the environment, boost creativity and enable the seamless development of more intelligent inner-city environments. To address challenges across these domains, the Delphi method was employed, engaging a diverse group of experts to identify key issues and assess their relative importance, and SPSS software was used to analyze the data. The primary objective is to determine which smart building domains should be prioritized for citywide smartification and how they reinforce other building domains. Ultimately, this focus on innovation strengthens the sustainability of smart cities by analyzing the impacts of building performance across various domains and promoting citywide innovation networks. By examining the unique features of smart buildings, this research underscores innovation as a driving force for reshaping the cityscape. The aforementioned approach significantly advances smart city development, as technologically enhanced buildings are the foundation of innovative cities. In the absence of intelligent building practices, achieving smart cities is impossible; cities are fundamentally shaped by their buildings. Smart buildings take the first essential step toward creating smarter urban environments.

Keywords: smart cities; smart buildings; urban innovation; buildings innovation; integration of building domains

1. Introduction

The trend of urbanization has significantly changed how people view modern living standards. This is evident in the 2018 Update of the World Urbanization Outlook. Considering the recent growth in urban population and job creation for individuals, there have not yet been serious efforts made in the area of education and awareness for residents. One of the main problems and challenges is that at present, 55% of the world's population lives in urban areas. **Figure 1** shows the urban and rural populations, and this figure is projected to reach 68% by 2050 [1]. Therefore, education and awareness for the acceptance of smart technologies should be a top item in the government's plan. However, the fast urbanization has not come with enough progress in urban services. The strong understanding that citizens need to take part in building their tech-driven city still seems to be very difficult for local people [2].

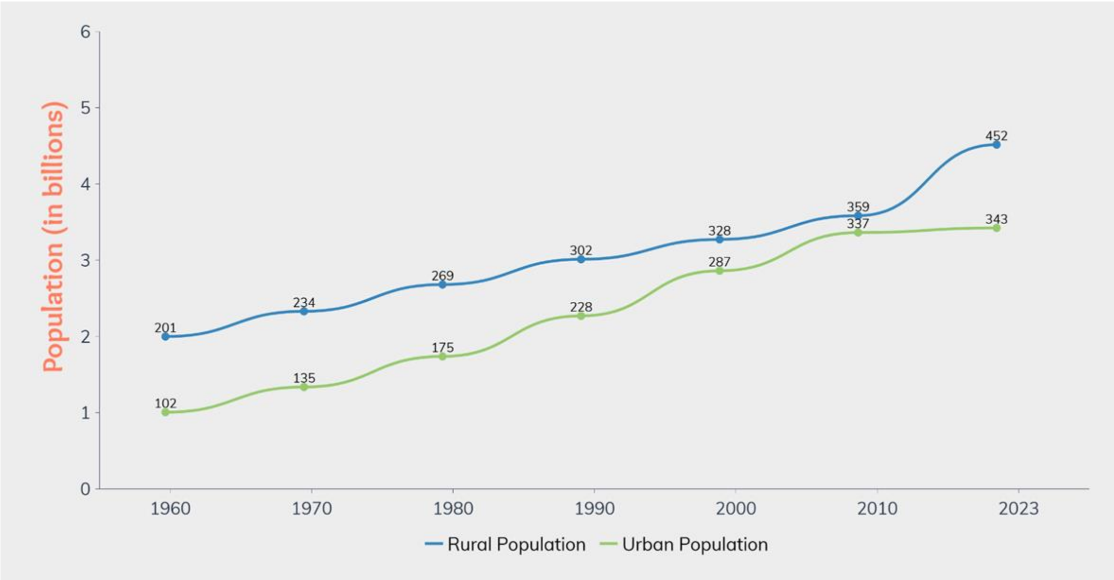

Figure 1. Number of people living in urban and rural.

Cities are facing numerous challenges such as too many people, flooding, slow public service delivery, and more. In light of these serious challenges, the idea of a smart urban center has arisen as a hopeful solution on the global stage [3]. In the field of intelligent urban development, the essential role of technology must be noticed, especially the role that smart buildings play. Smart buildings, commonly known as the thinking centers, are the main part of smart cities, and without truly intelligent buildings, a fully developed smart city cannot exist [4]. These buildings are basically self-sufficient structures that form the base of intelligent urban environments [5]. Given that major cities, even though they only cover 5% of the planet's land area, are responsible for a remarkable 75% of global fossil fuel use, it is our responsibility to take real actions. These actions should not only reduce the rising use of fossil fuels in cities but also deal with problems of high energy demands in urban areas during a time of rapid urbanization and a big rise in energy needs [5]. In this case, using smart buildings in the system of smart cities is not just a future idea; it offers a real and quick solution for now and later. The growth of smart buildings is not just about city planning or building systems; instead, it acts as a main push for progress in city development and the country's economy. Moreover, it improves the overall quality of living for city residents, who are encouraged to embrace the demands of smart and eco-friendly world issues [6].

In addition to the above, the right to legal exchange plays an important role in creating the infrastructure necessary to implement smart building technologies in urban environments. These technologies require infrastructure that must be secured from private land, so the right to legal consensus serves as a means of maintaining a balance between individual property rights and social needs [7]. Also, protecting privacy and data in smart city buildings presents challenges. These challenges allow the implementation of projects by exercising the right to consent without the need for full ownership of land and reduce the contradictions between public needs and private rights [8]. In this regard, legal standards and frameworks are especially important in the field of data protection.

In this context, a useful framework has been proposed by the British Standards Organization (BSI) specifically in their comprehensive and free report, PD 8100 on Smart Cities [9]. As a guide for urban decision-makers and project managers, the framework sets out how to use innovative technologies in cities and helps them meet technical and legal requirements. Finally, standards at different levels help guide urban leadership and decision-making managers, enabling them to effectively implement smart projects in compliance with technical and legal requirements [10].

This study looks into smart buildings and their important role in the progress of smart cities. With rising urbanization and the urgent need for sustainable solutions, **Table 1** shows why this research is important by pointing out main gaps in integrating smart technologies to solve challenges highlighted in previous research.

Table 1. Some of the reasons in previous studies that show the necessity of doing this research.

Author(s)	Title of Paper	Summary
José and Rodrigues [2]	A review on key innovation challenges for smart city initiatives	This study examines fundamental gaps between innovation in smart urban areas and the core features of digital innovation. These gaps underscore the necessity for new digital platforms that can provide technical solutions in an accessible and easy-to-use format for numerous cities, while also emphasizing innovation, technological neutrality, and data interoperability.
Hoang [11]	Impact of integrated artificial intelligence and Internet of Things technologies on smart city transformation	This research explores the incorporation of artificial intelligence and Internet of Things technologies to tackle the challenges faced by modern cities and to improve citizens' quality of life. When effectively combined, AI and IoT provide transformative solutions for enhancing smart infrastructure and optimizing public services.
Apanaviciene et al [6]	Optimisation of energy and life cycle costs via building envelope: a BIM approaches	This study highlights the importance of integrated energy management through Sunthalpower, an innovative solar generator system that combines various technologies to maximize solar energy use for powering structures in a way that is both efficient and environmentally sustainable, underscoring the need for energy integration in smart buildings.
Apanaviciene et al [1]	Smart building integration into a smart city (SBISC): Development of a new evaluation framework	The findings of this article show that smart buildings, leveraging the capabilities of smart cities in the domains of smart energy, smart transportation, smart living, and smart environment, possess a higher potential for achieving increased intelligence.
Kim et al [5]	Smart building integration into a smart city: Comparative study of real estate development	Collecting, analyzing, and analyzing real-time data for urban management systems and building maintenance systems enables the adoption of informed decisions in the fields of energy, mobility, and environmental concerns. At the same time, it ensures an enhanced quality of life and productivity for individuals inside structures and cities.
Altaf et al [12]	A systematic review of the smart energy conservation system: From smart homes to sustainable smart cities	The three main obstacles to smart cities are cooperation, flexibility, and decentralization. Overcoming these obstacles is essential for the advancement of connected homes within sustainable connected cities.
To et al [13]	Building professionals' intention to use smart and sustainable building technologies—An empirical study	Building experts considered digital systems for monitoring people's movements to be less significant. The most and least critical features highlighted a safety-privacy dilemma. This challenge pressures construction professionals to design improved premises security and monitoring systems without compromising individuals' privacy.

1.1. Definition of smart buildings

A smart building is any structure that employs automated procedures to manage various building activities, including heating, ventilation, air conditioning, lighting, security, and other systems [11]. Smart buildings are characterized by their capacity to adjust to user requirements through advanced automation and data analysis, creating a responsive environment [12].

In the early 1960s, smart buildings were merely mechanical concepts reflecting potential innovation in building design through technical and scientific advancements

[13]. The first definition of a smart building was first introduced in 1989 by the Intelligent Building Institute of the United States. It was defined as a structure that delivers an efficient environment through the optimization of its architecture, systems, services, and their interconnected relationships. Over time, emphasizing operational efficiency, the effectiveness of urban residents, and the utilization of information and communication technologies [1].

The transition from traditional buildings to smart buildings involves the incorporation of cutting-edge technologies, including automation systems, data analytics, and the Internet of Things (IoT), to optimize building performance, enhance energy efficiency, ensure environmental sustainability, and improve occupant comfort by enabling real-time responsiveness to environmental changes and user needs [14].

Recent research defines a smart building as a framework that incorporates technology to enhance operational efficiency, performance, and occupant comfort. Smart buildings leverage technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) for instant real-time decision-making and automated processes, thereby improving operational efficiency and ensuring occupant safety [15]. These structures are thoughtfully engineered to maximize energy efficiency and resource utilization by implementing advanced systems focused on energy management, safety, and user comfort [16].

A key assessment tool employed to evaluate the intelligence of buildings is the Smart Readiness Indicator (SRI), introduced by the European Commission. The SRI primarily assesses the degree of automation and energy efficiency in smart buildings [17]. The central aim of smart buildings is to establish a comfortable living and working environment for occupants while simultaneously minimizing operational costs by promoting efficient energy and resource management [18].

1.2. The interconnection of buildings and smart cities

Smart devices in urban areas require strong energy networks and advanced transportation systems. In this context, smart buildings become even more intelligent and play a leading role in the transformation. To achieve this, effective management and coordination of various processes and technologies are necessary. This calls for the development of digital infrastructures, which are crucial for bringing about a significant improvement in the efficiency of smart environments [19]. Smart buildings bring sustainable amenities and conditions to urban centers, catering to the lifestyles of their inhabitants while enhancing and elevating them [20]. These buildings can become more sophisticated by utilizing the capabilities of smart cities in areas such as smart energy, smart transportation, smart living, and smart environments. Although smart buildings and smart cities are different ideas, their combination emphasizes the need for coordination and cooperation to leverage the benefits of the environmental assets and technological potentials they both provide [1].

The transition from intelligent residences to eco-friendly, connected urban areas represents a strategic pathway to overcoming three main obstacles in developing smart urban environments: interoperability, flexibility, and decentralization [5]. Humanity presently finds itself amidst a data revolution that furnishes novel insights into cities, empowering policymakers to gain a deeper understanding of citizen expectations visà-vis "smart" buildings and urban settings. While exploring the requisite infrastructure to support smart environments, it is equally imperative to ascertain the optimal modes of citizen interaction with these dynamic ecosystems [21]. Information and communication technology emerge as pivotal components in addressing urban challenges through the lens of "smart" solutions [22]. Although a globally recognized definition of a smart city remains elusive, a consensus among researchers underscores the centrality of information and communication technologies as the bedrock of smart urbanization [23]. The path to smartifying hinges on city governments' ability to transcend a narrow focus on specific technologies or the emulation of established global products. Instead, it necessitates comprehensive studies that take into account the specific requirements and complexities of each city [24].

In the realm of a smart environment, the orchestration of several integral components is imperative to attain the vision of a fully realized smart city. These indispensable elements encompass smart buildings (which include smart homes), smart networks, and smart meters, all of which converge to shape a comprehensive smart urban ecosystem. Their seamless integration is critical for building truly smart and sustainable urban areas [25]. The acceptance of the concept of smart buildings relies on support from senior management, stakeholders in energy companies, and construction firms, with mobilization for this purpose already observable within these organizations. Furthermore, information and communication technology emerge as a pivotal component in addressing urban challenges through the lens of "smart" solutions. However, the process of adopting this type of technology in construction or existing buildings is still in its early stages [26].

A structured framework for organizing smart city services is delineated in Kim and Yang [24], emphasizing three key facets: a) The advancement of eco-friendly intelligent city service indicators, grounded in the amalgamation of environmentally sustainable smart city principles and sustainability criteria. b) The elucidation of the intricate relationship between sustainable smart city services and their interplay with broader conceptualizations of smart cities. c) The articulation of an evolutionary paradigm by modeling the progression of services within the context of sustainability, discerning the unique characteristics of smart cities and their evolving nature. A salient hallmark of smart cities is their interdependence with existing efficient urban systems [27], with smart buildings standing as one of the linchpin components within these city systems.

Two distinct perspectives exist concerning smart cities: one emphasizes real-time monitoring, efficient governance, and the reinforcement of public safety and security through robust information and communication technology infrastructure, while the other champions innovation, creativity, entrepreneurship, and inspiration, fostering an environment that harnesses the ingenuity of smart citizens [28]. It is the people who consume energy, not the buildings themselves [26]. Indeed, the efficacy of smart buildings hinges upon the engagement of intelligent consumers—citizens who actively participate in intelligent energy consumption practices [29]. Ultimately, a smart city is one that continually advances its performance in meeting the evolving needs of its citizens, embodying a commitment to perpetual improvement and enhancement [30].

1.3. Performance metrics of smart buildings

Smart buildings assume a pivotal role in fulfilling the multifaceted needs of a smart city. They seamlessly integrate state-of-the-art technologies, enabling them to operate with energy efficiency, promote sustainability, and enhance the overall living experience for residents [31]. When it comes to delivering intelligent services, residential buildings hold an advantage over their commercial counterparts. This stems from the fact that residential buildings typically feature less intricate technical equipment and exhibit more straightforward performance requirements. In contrast, constructing models for commercial buildings proves to be a more intricate endeavor, given the heightened complexity associated with accommodating diverse occupants and specialized functionalities [32].

Given that the majority of human life unfolds within indoor environments, it follows that buildings serve as a cornerstone for the global landscape of electricity consumption and carbon dioxide emissions [33]. All new buildings are projected to achieve carbon-neutral status by 2050. Fifty percent of existing buildings will reach carbon-neutral readiness levels by 2040, and more than 85 percent will be carbon-neutral by 2050 [34]. Currently, the vast majority of buildings function as inactive energy consumers, isolated from the external world. To align with the objectives of power companies and overarching policy goals, there is an urgent need to transition consumers from being passive and unresponsive energy users into active contributors within the broader power system [35].

An urban evaluation framework must be established to assess the functionality of diverse intelligent technology applications concerning carbon emissions. Notably, intelligent energy networks, intelligent advanced water management systems, and sensor-based waste collection mechanisms have proven effective in reducing carbon footprint and enhancing overall environmental sustainability [23]. Furthermore, the widespread integration of smart buildings, with solar energy playing a central role, greatly supports global initiatives to reduce the environmental footprint of the construction and building industry [36].

Table 2. Smart building performance categories.

Performance	Performance outcome
Occupant comfort	Smart buildings take into consideration occupants' behavior and strive to enhance their comfort levels.
Energy efficiency	Smart buildings have the capability to significantly reduce energy consumption and associated costs.
Time savings	Automation of daily routines within smart buildings can result in substantial time savings.
Safety	Smart buildings are equipped with fire and gas leak detection systems, self-diagnostic capabilities, and advanced warning mechanisms, thereby enhancing safety levels.
Expert systems	Embedded systems in smart buildings retain domain knowledge.
Healthcare	Health-related considerations hold paramount importance in smart buildings, offering services including ideal temperature, air quality, and lighting conditions.
Service delivery	Smart building services can enhance the quality of life for elderly and disabled individuals by creating comfortable, secure, and supportive living environments.

In contrast, technologies such as smart windows and gray water recycling within smart homes, while beneficial, have demonstrated comparatively lower environmental performance. For instance, during scorching summer days, smart windows can adjust their light absorption properties to limit sunlight penetration, thereby reducing the need for cooling within the enclosed space. This practice translates into substantial electricity savings [23]. The main goal of an energy management system is to accomplish optimal energy acquisition and usage across the entire organization, minimizing energy expenses without impacting productivity and reducing environmental impacts [37]. The performance of smart buildings is divided into seven distinct areas, as presented in **Table 2**.

1.4. Key features of smart buildings

Smart buildings are distinguished by their incorporation of intelligent measurement systems, information and communication networks, security apparatuses, and responsive systems capable of interacting with both occupants and environmental conditions [38]. This enables the provision of a comfortable indoor environment across varying seasons.

Both smart cities and smart buildings share a common mission: to serve humanity by delivering rational and personalized solutions, thereby improving the standard of living for individuals [1]. Nonetheless, smart homes and buildings, by ensuring efficient environmental monitoring and the optimization of critical parameters, play pivotal roles in achieving long-term sustainability [39].

It's essential to distinguish between smart buildings and other sustainability-focused building concepts such as zero-energy buildings or passive buildings. While the latter are primarily concerned with sustainable features, smart buildings go beyond sustainability and leverage advanced technologies to accomplish an ideal balance between convenience and sustainable efficiency [13]. The design process for smart buildings also deviates from conventional building design, incorporating elements that facilitate learning from occupants, adaptation to their lifestyles, and decision-making regarding the adjustment of multiple engineering systems. A "smart" building comprises a nexus of elements including hardware, software, and communication networks [40].

The seamless integration of physical systems with cutting-edge Internet of Things and cloud-based control technologies, powered by advanced communication engineering, facilitates real-time monitoring and management. This, in turn, results in enhanced energy efficiency and superior thermal livability [41]. As a result of these advancements, designers and architects envisioning the buildings of the future are equipped with comprehensive knowledge of every aspect of a building, with the sole exception being the implementation of the software component integral to smart buildings, which is crucial for optimizing building performance and sustainability [40].

Irrespective of whether cities and buildings are labeled as "smart" or "intelligent," the core concept of "intelligence" hinges on the building's capacity to interact with individuals and society. The "intelligent" aspect, in particular, strives to enhance the system's interaction with humans [42]. Human-object communication capabilities in IoT devices also allow for remote intervention across various applications, creating new efficiencies in response and control. One core function of these IoT devices is real-time data collection, which involves monitoring environmental and physical conditions that guide subsequent automated actions by embedded operators [43]. This technology underpins smart systems infrastructure, from smart buildings to more expansive systems such as smart cities [44].

This software component, often residing in the cloud, constitutes a complex dimension of building management, primarily centered around data storage. Given the vast volume of data involved, conventional approaches must undergo modification to align with emerging requirements, ensuring effective management of this increasing complexity and the successful integration of smart technologies in building management [45].

The advent of 5G wireless networks stands as a pivotal solution in the framework of intelligent urban areas, serving as the connective tissue linking countless Internet of Things (IoT) devices. Notably, smartphones and vehicles are emerging as potential communication and computational resources within smart cities, characterized by their abundance, expansive coverage, and high urban density [46]. In this landscape, the incorporation of intelligent technologies into buildings—enabled by the Internet of Things—is pivotal in improving user comfort and advancing technological capabilities. The deployment of these systems strives to minimize energy expenses while maintaining the building's environmental sustainability throughout its life cycle [47].

To capture the movement patterns of citizens, mobile phone wireless signal tracking is employed, representing a departure from previous methodologies. This approach allows for real-time anomaly detection, applicable to both individuals and vehicles, and can extend to specific locations or even within building interiors. The creation of smart buildings within smart cities necessitates advanced technologies capable of supporting efficient and sustainable energy strategies [48].

1.5. Smart building technologies

Smart meters are essential for managing household energy consumption from electrical appliances and heating/cooling systems, as they transmit data to centralized smart home energy management systems through communication networks. This data is then used by optimizers or controllers to make informed decisions, ensuring coordinated and optimal energy consumption and on-site electricity generation [49]. The replacement of residential smart meters is only part of the costs associated with installing a smart grid system [26]. However, with IoT interlinking, smart meters allow home occupiers to remotely manage their energy usage and gain detailed insights into their expenditure habits. Sophisticated analytical tools can analyze this data to provide tailored recommendations for energy efficiency [41].

In the contemporary landscape, terms like "Internet of Things," "smart home," and "ubiquitous computing" have transcended academic discourse and become integral to everyday life. Digitalization is rapidly evolving not only in terms of technological solutions but also in terms of applications in buildings. Understanding the optimal use of existing and emerging digital technologies throughout the building life cycle and how these technologies can contribute to making buildings more sustainable is essential.

The incorporation of intelligent home technology within larger intelligent urban frameworks enables the amalgamation of information gathered from structures with other sources, including traffic patterns, weather forecasts, and energy consumption patterns. This synergy between smart buildings and smart city infrastructure enhances emergency response services [42]. Sustainability stands as a fundamental pillar in the development of smart cities. Smart devices and services have become integral components of smart urban environments, and the application of city information management fosters effective solutions for urban construction challenges [46].

1.5.1. Blockchain technology and its impacts

Blockchain technology is poised to enhance the lives of smart city residents by providing improved availability of public transit, reduced travel durations, and heightened data security standards. Furthermore, it supports the development of community energy optimization systems for intelligent urban areas, offering enhanced data accessibility and the ability to minimize reduced expenses and inefficiencies in energy generation and distribution [50]. Additionally, blockchain technology enables the secure management of sustainability data, such as energy consumption and carbon emissions, ensuring transparency and accountability within smart urban frameworks [51].

In the realm of smart buildings, blockchain creates interoperable systems that communicate and exchange data, ensuring privacy and data governance for residents living in smart homes within the broader concept of smart cities [52].

1.5.2. Advanced energy management systems

Transforming conventional buildings into intelligent, energy-efficient facilities depends on the implementation of advanced energy management systems designed to reduce usage and boost efficiency. For these systems to succeed, active resident participation is essential, requiring an understanding of their energy-saving behaviors [37]. Additionally, the design of future smart buildings will necessitate sophisticated energy management systems capable of coordinating various energy subsystems both economically and efficiently. These systems should integrate seamlessly within a connected network, enabling real-time data exchange across the community [49].

The Internet of Things (IoT) facilitates the integration of smart grids, facilitating smooth interaction between solar systems and the wider energy network [41]. Solar energy, with its abundance, availability, and suitability for remote locations, is especially well-suited for building-based microgrids, where reliability and adaptability are prioritized. To meet the dynamic demands of urban spaces, scalable and flexible energy solutions are needed [49]. The overarching goal of building energy optimization is to attain high levels of energy performance and reduced greenhouse gas output, all while remaining cost-effective and maintaining consumer comfort and preferences [53]. Incorporating renewable energy sources in buildings, therefore, offers notable benefits for climate, health, and economic well-being within smart cities.

1.5.3. IoT for energy efficiency and smart automation

The incorporation of IoT technologies in intelligent structures significantly enhances energy efficiency. Researchers analyze energy usage trends to create predictive models and improve algorithms for intelligent building management systems [54]. Smart sensors and devices collect data to optimize energy use in real-time, enabling more sustainable building operations [55].

IoT automates multiple building systems, including heating, ventilation, and air conditioning (HVAC), improving operational efficiency and occupant comfort [56]. IoT technologies enhance automation systems in intelligent structures, allowing continuous monitoring and management of systems like HVAC, lighting, and security through interconnected devices and sensors [57]. Facility managers can remotely monitor and control building systems, leading to enhanced efficiency and user comfort [58].

IoT-enabled lighting systems adjust depending on usage patterns and environmental factors, reducing energy inefficiency and improving user experience [59]. These smart lighting systems monitor and control lighting with sensors and IoT devices, contributing to energy performance and user occupant satisfaction in advanced buildings [60]. By adjusting lighting based on occupancy and natural light levels, these systems achieve significant energy savings and enhance the user experience [61].

IoT for enhanced safety and predictive maintenance

IoT technologies play a pivotal role in improving building safety by integrating advanced sensors that monitor environmental conditions such as air quality, fire hazards, and structural integrity. These sensors provide early warnings, enabling timely interventions to mitigate risks [62]. Additionally, IoT enables predictive maintenance of building systems by continuously monitoring their performance and identifying potential issues before they lead to failures. This reduces downtime, lowers maintenance costs, and enhances overall operational reliability [63].

IoT-driven personalization and sustainability

IoT fosters greater personalization for building occupants by offering tailored services such as automated temperature adjustments, customized lighting, and smart appliance control based on user preferences. Furthermore, IoT supports environmental sustainability by optimizing resource consumption, including energy and water, and minimizing waste through real-time monitoring and automated adjustments [43].

In particular, IoT significantly enhances residents' lives within smart buildings by increasing security, environmental compatibility, and convenience [64]. Smart buildings hold the promise of home appliances that can anticipate occupants' needs and act accordingly at the push of a button. By generating substantial data streams, these buildings enable researchers to utilize machine learning and big data analytics to manage, process, and gain insights from this wealth of information [32].

IoT integration, when combined with information and communication technology (ICT) and other innovative technologies, holds the potential to revolutionize smart cities. A fundamental requirement for IoT-enabled smart cities is the swift and timely sharing of critical information, with minimal reporting delays. Data must be continually updated at short intervals to ensure the city's sustainability and environmental friendliness through the constant monitoring of IoT-enabled sensors [65].

Based on recent research, the integration of IoT in smart building technology enhances residents' quality of life by automating tasks and enabling intelligent, lowintervention decisions that facilitate a more streamlined living experience. Additionally, IoT devices embedded in building operations contribute by integrating system elements both horizontally and vertically, allowing residents access to data and operational insights, enhancing management efficiency across departments [44].

2. Materials and methods

In this study, at the first stage, the scientific works of authors in the field of smart buildings and smart cities published in scientific databases were analyzed. Relevant articles were carefully examined, and through the synthesis method, the main concepts related to the research topic were extracted. Subsequently, using the comparison method, the perspectives and methodologies employed by other researchers—from traditional buildings to the role and function of smart buildings within smart cities—were reviewed. Furthermore, the inductive method was used to derive general conclusions from specific data, and finally, based on the deductive method, the research hypotheses and findings were logically analyzed and evaluated.

The Delphi method serves as an efficient and effective approach for assembling experts to engage in discussions, brainstorm, and systematically organize information with the objective of developing a valid instrument, achieving consensus on a particular topic, identifying common factors, or predicting trends [66]. A succinct and broadly applicable definition was originally provided by the Rand Corporation, which defined the Delphi method as a technique for "eliciting and refining group judgments" [67]. This underscores the idea that "when something can be clearly defined, it is no longer progressing". This dynamic process not only facilitates the convergence of diverse viewpoints but also encourages the evolution of ideas, allowing participants to continually refine their judgments based on collective insights and emerging trends in the field. Thus, the Delphi method acts not only as a tool for achieving consensus but also as a catalyst for innovative thinking and informed decision-making in complex areas of study, contributing to ongoing research and advancement.

2.1. Research design

In this research, questionnaires were administered to experts in two rounds. In the initial round, the sum and average of the opinions were compiled, and experts were subsequently asked to reconsider their responses in light of these averaged opinions. Following this feedback, experts had the opportunity to reassess their original responses in conjunction with the new information, with the option to add, modify, or retain their initial responses. The number of iterations was determined by each group, aiming to achieve a strong consensus or identify the absence of consensus. One of the major obstacles and challenges in this study was the limited collaboration with experts. Consequently, this study was conducted in two phases to analyze the results effectively.

2.1.1. Study population

The study includes a total of 20 participants from various professional backgrounds, ensuring a well-rounded perspective on the topic. This group consists of two employers in the construction industry (construction managers), one consultant specializing in urban planning and smart technologies (urban planning consultant), one contractor with extensive experience in building construction (experienced contractor), four academic members with expertise in smart cities, smart buildings, or related fields (university professors), twelve professionals actively involved in different sectors of the construction industry, including architecture, engineering, and technology implementation.

Among these participants, 17 individuals demonstrated a comprehensive understanding of smart building and smart city concepts, held educational qualifications beyond a bachelor's degree, and possessed work experience ranging from 5 to 15 years in building construction. This ensured that the majority of participants had a strong technical background relevant to the research. Additionally, three end-users of buildings, who do not have a technical background, contributed insights from a consumer perspective. Their input was crucial to assess the readiness and willingness of the general public to adopt smart city technologies, enriching the research with a broader viewpoint.

2.1.2. Delphi method steps

Step 1: Defining the problem: The initial phase of this research involved a thorough review of existing literature to gain a comprehensive understanding of the importance of smart buildings within the context of smart cities. Following this review, a total of 64 questions related to the research objectives were developed and organized into seven key categories. This categorization serves as a foundational framework for the study, guiding its objectives and facilitating targeted data collection on crucial aspects of the research topic.

Step 2: First round of individual surveys: In the first round of the Delphi method, each expert was presented with the defined research problem and asked to provide their independent responses. A diverse team of 20 experts was assembled, including university professors, experienced construction professionals, and residents. This team was introduced to the objectives of the study and the critical significance of the research topic.

Step 3: Summarizing the responses: During this phase, the responses collected from the first round were systematically compiled and summarized, while maintaining the confidentiality of the participating experts. Each question was assessed using a 5-point Likert scale (as shown in **Table 3**), ranging from "not important at all" (1) to "very important" (5), to evaluate the significance for smart city development. The detailed description of the scale is provided in **Table 3**.

Table 3. Likert scale.

Verbal expression	Likert scale value
Very important	5
Very	4
Relatively	3
A little	2
At all	1

The fourth stage: Second round of feedback and discussion: In the fourth stage, the summarized results from the first round were presented to the participants. These results included the average opinions gathered from the initial round of responses. Participants were then invited to reevaluate their initial answers, considering the collective insights of the group. This iterative process aims to promote consensus and refine expert opinions as the Delphi method progresses.

2.1.3. Data validation

To ensure the validity of the data, response sheets were initially distributed to a select group of experts. Their task was to complete these sheets, helping to identify potential errors in the questionnaire and suggest necessary improvements. Following this, the reliability of the questionnaire items was assessed for each question group using Cronbach's alpha coefficient, computed using SPSS software. A coefficient value above 0.7 is generally deemed acceptable for reliability. In this instance, the coefficient obtained was 0.976, indicating that the questionnaire items exhibit extremely high reliability and affirming the trustworthiness of the data. This meticulous process reinforces the robustness and credibility of the data collected for the research. **Table 4** displays the results of the test for each category of questions.

Table 4. Validation of questions using Cronbach's alpha coefficient.

Category of questions	Number of questions	Reliability coefficient
The significance of intelligent buildings in the economic dimension of smart cities	8	0.820
The significance of intelligent buildings in the social dimension of smart cities	9	0.885
The significance of intelligent buildings in the environmental dimension of smart cities	11	0.906
The significance of intelligent buildings in the energy dimension of smart cities	7	0.851
The significance of intelligent buildings in the innovative dimension of smart cities	12	0.947
The significance of intelligent buildings in the technological dimension of smart cities	7	0.844
The significance of intelligent buildings in the integration dimension of smart cities	10	0.895
All	64	0.976

2.2. Methodological justification: Delphi and SPSS

The Delphi method was chosen for this research due to its structured ability to gather expert opinions and reach consensus on complex and evolving topics. This method enables the identification of key challenges and opportunities in adopting smart cities, particularly in developing contexts such as Jordan [68]. Its iterative feedback process and consensus-building approach enhance the reliability and novelty of the findings by uncovering expert-driven insights often overlooked by traditional methods [69]. This method is particularly suitable for topics that require expert input and the achievement of structured consensus or exploration of diverse perspectives [70]. Furthermore, compared to other research methods, the Delphi method is more suitable for exploring multi-dimensional expert perspectives in dynamic fields such as smart city initiatives [71].

SPSS is one of the most powerful tools for analyzing complex, non-numeric data, making it ideal for survey-based research [72]. It offers a wide range of statistical methods, including both descriptive and inferential statistics, along with useful data visualization features that improve the interpretation of results [73]. Moreover, its automation minimizes human error in analyzing data related to smart cities and buildings, enhancing the accuracy and reliability of results [74]. SPSS can efficiently manage and analyze large datasets, making it easier to uncover meaningful insights [75]. The software's user-friendly interface allows researchers, even those with limited statistical training, to conduct complex analyses with ease [76]. This feature is especially valuable for research teams working on smart cities [77].

3. Results

The characteristics of smart buildings have been systematically categorized into seven distinct areas: economic, social, environmental, energy, innovation, technology, and integration. This categorization serves as the framework for analyzing and interpreting the data collected through questionnaires. To evaluate the hypotheses, a one-sample Kolmogorov-Smirnov Test was conducted to assess the normality of the data distribution, followed by a Kruskal-Wallis Test to determine significant differences among groups. The following results highlight the importance of each area in the development and assessment of smart buildings.

3.1. Statistical analysis

In this study, the statistical tests were conducted to evaluate the research hypotheses: the one-sample Kolmogorov-Smirnov Test and the Kruskal-Wallis Test.

1) One-sample Kolmogorov-Smirnov Test: This test was employed to assess the normality of the data distribution. The purpose of this test was to determine whether the collected sample data originates from a normally distributed population. Assessing normality is a crucial step in statistical analysis, as many parametric tests (e.g., ANOVA) assume that the data follows a normal distribution. By performing this test, we aimed to validate the suitability of using parametric methods for further analysis.

Table 5. The result of Kolmogorov-Smirnov Test.

Sample size (*N*)	**140**
Mean	37.6571
Standard deviation	9.39904
Asymptotic significance (*p*-value)	0.002

According to **Table 5**, the results indicated a *p*-value of 0.002, which is below the conventional threshold of 0.05. This suggests that the null hypothesis of normality is rejected, implying that the data do not follow a normal distribution. Consequently, the use of parametric tests such as ANOVA is deemed inappropriate.

2) Kruskal-Wallis Test: Given the violation of normality, the Kruskal-Wallis Test was utilized as a non-parametric alternative to one-way ANOVA. This test aims to evaluate whether there are statistically significant differences in the median scores among multiple independent groups. The results, as presented in **Table 6**, indicate a test statistic (*H*) of 78.071 with 6 degrees of freedom and a *p*-value of 0.000, confirming that at least one group significantly differs from the others concerning the scores.

Table 6. The result of Kruskal-Wallis Test.

Variables Tested	Results
Test statistic (*H*)	78.071
Degrees of freedom (df)	6
Asymptotic significance (*p*-value)	0.000

The standard deviation of the dataset (9.39904), derived from the one-sample Kolmogorov-Smirnov Test, reflects the dispersion of the sample around the mean. Given the non-normal distribution of the data, the Kruskal-Wallis Test was appropriately selected to compare means across different groups. Subsequently, the Bonferroni post-hoc test was employed for pairwise comparisons.

The Bonferroni post-hoc test is a statistical adjustment used to address the problem of multiple comparisons. When conducting multiple hypothesis tests, such as comparing means across several groups, the Bonferroni correction is used to prevent an increase in the likelihood of false-positive results. The Bonferroni correction mitigates this risk by adjusting the significance level (alpha) according to the number of comparisons being made. Essentially, it divides the desired significance level (e.g., 0.05) by the number of comparisons to establish a new threshold for determining statistical significance. This ensures that even if individual tests show significance, the overall family-wise error rate is controlled.

3.2. Analysis of domain-wise statistical significance

Table 7 presents the probability values derived from pairwise comparisons between different domains across two rounds, as determined by the Bonferroni post-hoc test. These results underscore the significant differences between the domains in advancing smart cities, providing valuable insights into their relative importance. This table highlights significant data with *p*-values less than 0.05, emphasizing meaningful relationships between variables. This approach ensures that the focus remains on the statistically significant associations contributing to the study's core findings.

Table 7. Significant differences between domains in the development of smart cities.

Variable	**Comparable variable**	**Probability value**	
		First round	**Second round**
Economic	Environmental	0.000	0.000
	Innovation	0.000	0.000
	Technology	0.030	0.504
	Integration	0.104	0.000
Social	Environmental	0.004	0.000
	Energy	0.001	0.004
	Innovation	0.000	0.000
	Technology	0.000	0.001
	Integration	1.000	0.037

Table 7. (*Continued*).

Variable	Comparable variable	Probability value	
		First round	**Second round**
Environmental	Economic	0.000	0.000
	Social	0.004	0.000
	Energy	0.000	0.000
	Technology	0.000	0.000
Energy	Social	0.001	0.004
	Environmental	0.000	0.000
	Innovation	0.000	0.000
	Integration	0.000	0.000
Innovation	Economic	0.000	0.000
	Social	0.000	0.000
	Energy	0.000	0.000
	Technology	0.000	0.000
	Integration	0.002	0.000
Technology	Economic	0.030	0.504
	Social	0.000	0.001
	Environmental	0.000	0.000
	Innovation	0.000	0.000
	Integration	0.000	0.000
Integration	Economic	0.104	0.000
	Energy	0.000	0.000
	Innovation	0.002	0.000
	Technology	0.000	0.000

1) Economic domain:

- First round: There is a significant interaction with the environmental and innovation (p = 0.000), and technology (p = 0.030) domains, while showing no significant interaction with Integration (p = 0.104).
- Second round: The economic domain remains significantly related to environmental, innovation, and integration (p = 0.000), while showing no significant interaction with technology (p = 0.504).
    - The strong correlations suggest that economic factors play a crucial role in the development and integration of smart technologies and innovations within urban environments.

2) Social domain:

- First round: Significant relationships were found with environmental (p = 0.004), energy (p = 0.001), and innovation and technology (p = 0.000), while showing no significant interaction with integration (p = 1.000).
- Second round: It continues to show significant correlations with environmental (p = 0.000), energy (p = 0.004), innovation (p = 0.000), technology (p = 0.001), and integration (p = 0.037).
    - This indicates that social aspects significantly impact innovations and

sustainability efforts, enhancing the quality of life in smart cities.

3) Environmental domain:

- Both rounds: The environmental domain shows significant interactions with economic (p = 0.001), social (p = 0.004), energy (p = 0.001), and technology (p = 0.000).
  - This highlights the importance of environmental considerations in driving economic productivity and technological advancements in urban development.

4) Energy domain:

- Both rounds: The energy domain has significant relationships with social (p = 0.001), environmental (p = 0.000), innovation (p = 0.000), and integration (p = 0.000).
  - Effective energy management and sustainable practices are vital for enhancing social interactions and environmental sustainability in smart cities.

5) Innovation domain:

- Both rounds: Innovation significantly interacts with economic (p = 0.000), social (p = 0.000), energy (p = 0.000), technology (p = 0.000), and integration (p = 0.002).
  - Innovation is a central theme across multiple domains, emphasizing its pivotal role in the advancement of smart buildings and cities.

6) Technology domain:

- First round: Significant correlations with economic (p = 0.030), social (p = 0.000), environmental (p = 0.000), innovation (p = 0.000), and integration (p = 0.000).
- Second round: Maintains significant relationships with economic (p = 0.030), social (p = 0.001), environmental (p = 0.000), and integration (p = 0.000).
  - Technological advancements are crucial in transforming urban lifestyles and promoting the development of smart cities.

7) Integration domain:

- First round: Shows significant interconnections with energy (p = 0.000), innovation (p = 0.002), and technology (p = 0.000), while showing no significant interaction with economic (p = 0.104).
- Second round: Continues to demonstrate significance with economic (p = 0.104), energy, innovation, and technology (p = 0.000).
  - The integration of various domains facilitates innovation and efficient energy management, thereby enhancing the overall functionality and sustainability of smart cities.

The data analysis indicates that significant relationships exist among various domains in the context of smart cities, emphasizing the need for a holistic approach to urban development. Understanding these interactions can guide decision-making processes related to the implementation and optimization of smart buildings in urban environments, ensuring a balanced consideration of economic, social, environmental, and technological factors.

While the previous table highlighted significant differences among certain variable pairs, analyzing the pairs that do not show meaningful differences is equally important. This lack of significant difference may indicate consistency or convergence between key variables within the framework of smart buildings. **Figures 2** and **3** present a comparative analysis of variable pairs with no significant differences observed. Such analysis provides deeper insights into the balance among various dimensions of design and urban development, highlighting areas where integrated approaches may need refinement or reinforcement.

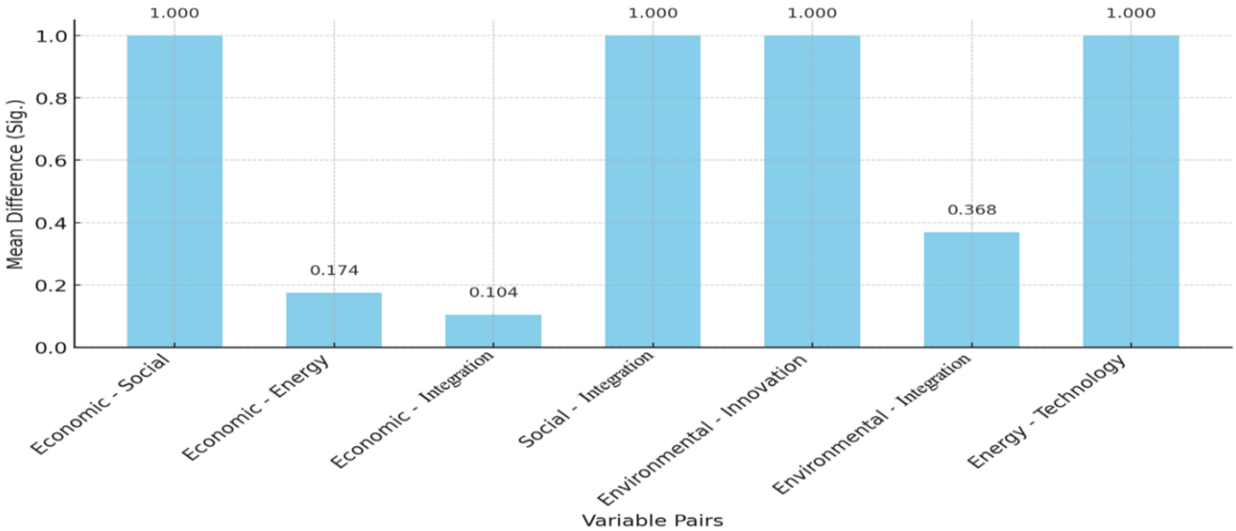

Figure 2. Mean difference results for round 1.

The bar chart (**Figure 2**) illustrates the mean differences (Sig.) for variable pairs in round 1, revealing no statistically significant differences across any of the comparisons (Sig. $\geq$ 0.05). For instance, pairs such as economic-social and environmental-innovation exhibit no substantial variation, demonstrating uniformity in their impacts. These findings underscore the interconnectedness of economic, social, environmental, and technological dimensions in the context of smart building assessments. This consistency advocates for a holistic, multidimensional approach in urban planning and smart city development, ensuring balanced consideration of all domains without prioritizing one over another.

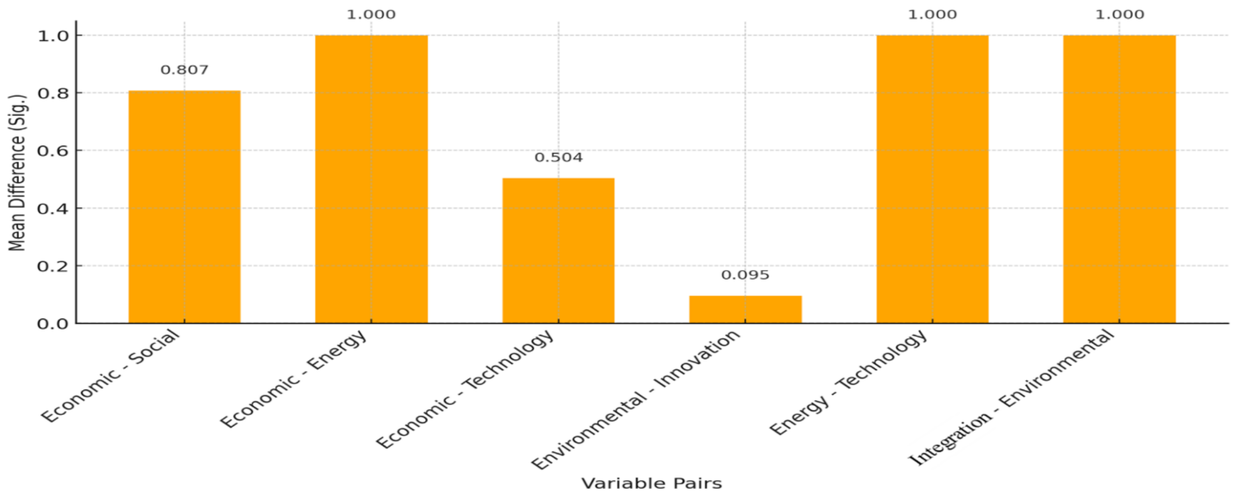

Figure 3. Mean difference results for round 2.

The bar chart (**Figure 3**) illustrates the mean differences (Sig.) for variable pairs in round 2. Similar to round 1, the results reveal that most variable pairs do not demonstrate statistically significant differences (Sig. ≥ 0.05). Notably, the environmental-innovation pair (Sig. = 0.095) approaches the significance threshold but remains outside the statistically significant range. This consistency across variable pairs suggests that the examined dimensions—economic, social, technological, and environmental—exert comparable impacts, emphasizing the stability and coherence of the framework. These findings underscore the importance of adopting an integrative and multidimensional approach to smart building strategies, ensuring that all dimensions are considered holistically. For urban policy and research, the lack of statistically significant differences supports the reliability of the model and reinforces the value of collaborative, cross-dimensional planning in achieving sustainable urban development objectives.

3.3. Evaluation of domains significance and key advancements

Figure 4 illustrates the mean importance of different domains along with the associated standard deviation bars, which reflect the variability in expert opinions across these domains. The data highlights the relative significance of each domain, with the standard deviation providing insight into the consistency or variability of responses among participants. The higher the standard deviation, the more diverse the expert opinions on the importance of that domain.

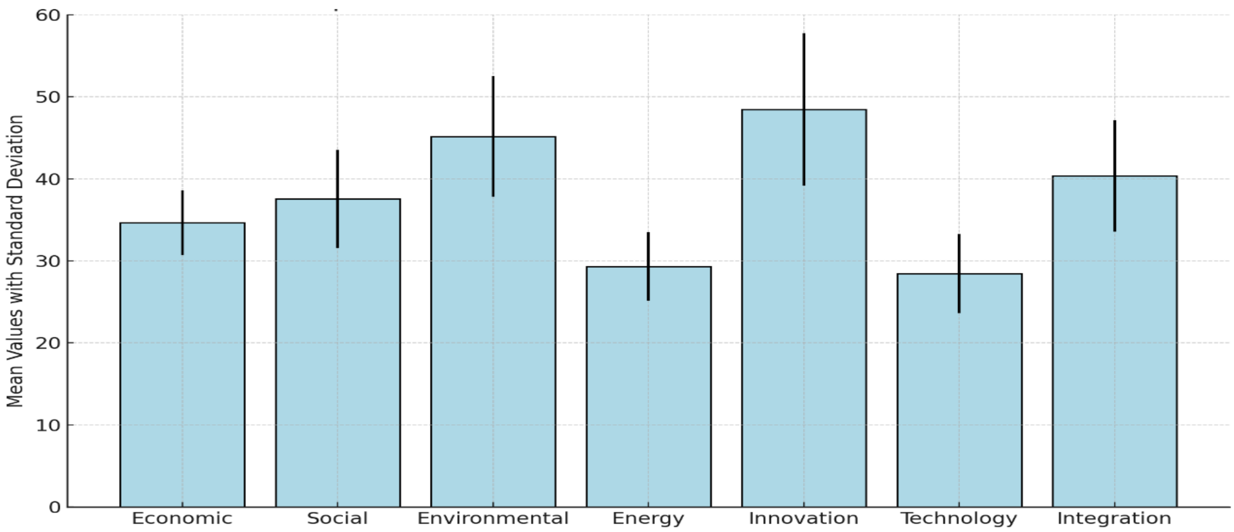

Figure 4. Mean importance of various domains with standard deviation.

1) Environmental and innovation domains: These two domains show the highest mean values among all domains, with prominent standard deviations. This suggests that both environmental and innovation aspects are viewed as highly important for advancing smart cities. The larger standard deviations indicate variability in opinions or impacts, highlighting that these areas may be influenced by diverse factors or have varying levels of importance across different contexts.

2) Integration and social domains: Both integration and social domains have moderately high mean values, with integration slightly surpassing social. The standard deviations, while smaller than those of innovation and environmental, suggest a

relatively consistent importance of these domains across the board. This reinforces the notion that integrating various systems and prioritizing social aspects are essential, though perhaps less variable or debated compared to environmental and innovation domains.

3) Economic domain: The economic domain has a lower mean value compared to the top-ranking domains but still holds moderate importance. Its smaller standard deviation implies a more uniform consensus on its role in smart city development. This likely reflects a shared understanding of the economic considerations in smart city projects, albeit seen as less critical than environmental or innovation factors.

4) Energy domain: This domain shows the lowest mean value, which might suggest that, within the context of smart cities, energy considerations are perceived as less critical compared to others. However, the narrow standard deviation indicates a consistent view, implying that energy factors are necessary but perhaps not as prioritized.

5) Technology domain: Technology also has a lower mean value with a small standard deviation. This could indicate that while technology is a backbone of smart city projects, its role might be taken for granted, with a consistent view that it supports but does not directly drive the most critical impacts alone.

Table 8 shows the comparison of two rounds of testing aimed at identifying key advancements in smart city domains, with the goal of pinpointing the most impactful areas for development and strategic focus. This research highlights specific domains—such as innovation, environmental quality, and integration—as crucial contributors to the sustainable growth and technological evolution of smart cities. To enhance understanding, this analysis compares these areas across both rounds.

Table 8. Comparison of two rounds of testing for identifying key advancements in smart city domains.

Index	Mean (Round 1)	Mean (Round 2)	Change
Economic	34.65	33.15	−1.50
Social	37.55	36.95	−0.60
Environmental	45.15	45.85	+0.70
Energy	29.30	29.95	+0.65
Innovation	48.45	51.10	+2.65
Technology	28.15	29.00	+0.85
Integration	40.35	42.75	+2.40

- Highest increase in innovation and integration: The innovation (+2.65) and integration (+2.40) domains show the most growth. This indicates a growing focus on the importance of innovation and coordination between different sectors in advancing smart city goals.
- Stability in environmental, energy, and technology domains: Environment (+0.70), energy (+0.65), and technology (+0.85) have slightly increased, indicating that these areas remain highly important and play a key role in smart cities.
- Decrease in economic and social domains: Economic (−1.50) and social (−0.60)

have declined. This decrease may indicate less focus on economic and social issues, while more attention is directed toward innovation, environmental sustainability, and energy.

Overall, these changes suggest that, in the process of advancing smart cities, priorities are shifting towards greater innovation and integration across sectors, while economic and social aspects receive relatively less attention.

4. Discussion

As evidenced by the study's findings and previous studies, the areas of innovation, environment, and integration with the highest scores have played a crucial role in the advancement of intelligent urban areas and sustainable buildings. The goal of this part is to provide insights that help deepen the comprehension of the effects of intelligent structures on the creation of intelligent urban areas and to accelerate the achievement of long-term progress goals. Furthermore, the importance of other domains, such as public trust and socio-economic factors, cannot be overlooked.

Successful examples of integrating innovation, environmentalism, and integration in smart buildings include Singapore, Amsterdam, and Dubai. Singapore, through its initiative to optimize energy consumption using the Internet of Things (IoT) and Artificial Intelligence (AI) to reduce costs and greenhouse gas emissions [78], highlights the importance of environmental considerations and technological integration. Amsterdam's solar city strategy, which reduces carbon emissions through sustainable management in solar plant implementation [79], clearly demonstrates the significance of innovation in creating smart cities. Similarly, Dubai utilizes AI and IoT for real-time building management and predictive maintenance, significantly improving energy efficiency and sustainability [80]. These examples underscore the vital role of combining innovation, environmental strategies, and integration in developing smart urban solutions. All of these designs underscore the critical role of digital innovations as transformative agents in promoting durability in urban life. Intelligent energy optimization systems represent a major advancement in building management, contributing to the development of more sustainable and energy-efficient structures [47].

On the other hand, the study reveals that progress in the realm of digital innovation has been comparatively slower than in other fields, with significant challenges observed in regions such as North America. Issues like cybersecurity threats and the digital divide have hindered the broad adoption of smart technologies, ultimately eroding public confidence in these advancements [81–83]. This highlights the need for addressing barriers to digital innovation to ensure widespread acceptance and trust.

In line with the study's emphasis on the pivotal role of innovation in shaping smart cities, cities such as Amsterdam and Copenhagen exemplify how the integration of AI and IoT in energy management systems has been instrumental in advancing urban sustainability and driving technological progress [84,85]. These examples highlight the imperative of technological advancement in the development of smart cities.

Furthermore, the study's recommendation to build public trust in digital platforms resonates with Dubai's citizen-centric approach. By harnessing big data and social media, Dubai has successfully enhanced public engagement, transparency, and trust in its smart city initiatives [86,87]. This underscores the importance of ethical considerations and inclusive strategies in the pursuit of smart urban development.

Moreover, studies show that, without a genuine focus on sustainability, cities will not be able to achieve smartness [2]. This study builds on these perspectives by illustrating how balanced attention across economic, environmental, and technological dimensions fosters the resilience of smart systems and encourages sustainable practices across urban frameworks. For instance, Bandauko and Arku [88] highlight the socio-economic challenges faced by African cities like Nairobi and Lagos, emphasizing the need for sustainable urban development strategies that align economic growth with environmental protection. Similarly, Al-Dabbagh [89] discusses Dubai's efforts to integrate green building regulations and eco-friendly initiatives, showcasing how environmental considerations can be harmonized with socio-economic goals.

The research highlights that, following innovation, the environmental domain is crucial. Aligning environmental, social, and economic needs ensures sustainable outcomes, strengthens energy efficiency, optimizes resource management, and enhances the functionality of intelligent cities. Similarly, Al-Dabbagh [89] highlights Dubai's sustainable smart city initiatives, which integrate green building regulations and eco-friendly practices to balance socio-economic growth with environmental protection, further illustrating the importance of aligning environmental and urban development goals.

Moreover, the integration of nature-based solutions, as discussed by Carvalho [90], reinforces the role of sustainable practices in urban planning. These solutions, combined with technological advancements like AI and IoT, as explored by Anwar and Sakti [91], enable cities to enhance sustainability assessments and optimize urban growth predictions. Such integrations not only improve energy efficiency and resource management but also foster public trust and acceptance, as highlighted by Habib et al. [92] and Neupane et al. [81], who emphasize the importance of trust in technology and government for the successful adoption of smart city initiatives. Additionally, Waclawek et al [93] underscores the significance of public-private partnerships and community-centric business models in addressing urban challenges, while Tekin and Dikmen [94] stress the need for inclusive citizen engagement to ensure accessibility and social equity in smart city development. By prioritizing these aligned strategies, cities can achieve holistic smart development, ensuring both environmental sustainability and improved quality of life for citizens.

Finally, the third domain with the highest impact on smartification is integration. These findings indicate that building integration can contribute to enhanced coordination among various components of a smart city. The study's emphasis on integration as a catalyst for smart city development aligns with Kamvysi et al. [95], who highlight the importance of integrated frameworks like Quality Function Deployment (QFD) in designing targeted urban strategies. This study underscores that effective integration enhances coordination, optimizes resource management, and improves urban functionality. This synergy demonstrates how prioritizing integration can address complex urban challenges while fostering sustainable and adaptive smart cities.

5. Conclusion

This research highlights the essential importance of innovation, environmental considerations, and integration in advancing smart cities and eco-friendly buildings. Our findings reveal that innovation is the most influential factor, acting as a catalyst for enhancing urban environments and enhancing the well-being of residents. The establishment of innovation ecosystems at the urban level is crucial for promoting more intelligent and environmentally sustainable urban areas.

The environmental dimension is equally vital, emphasizing that intelligent energy management in intelligent structures is vital to guaranteeing the sustainability and resilience of urban environments. By aligning environmental strategies with socio-economic needs, cities can achieve comprehensive and lasting outcomes.

Integration emerges as the third crucial factor, facilitating coordination among various components of smart cities. This enhanced integration optimizes resource consumption and supports a seamless exchange of information, paving the way for a smart and sustainable ecosystem that significantly improves the quality of life for residents.

In conclusion, the successful realization of smart cities hinges on a holistic approach that embraces innovation, prioritizes environmental sustainability, and fosters integration. Furthermore, the importance of other areas cannot be overlooked. As cities continue to evolve, these domains must be effectively implemented to address urban challenges, ensuring that the aspirations of smart cities are not only met but also exceeded.

6. Limitations of the study

A primary limitation of this study was the limited access to specialists, which hindered the scope of expert input. Despite efforts to engage with a wide range of professionals, some individuals were unable or unwilling to participate. This challenge impacted the depth of the insights gathered from experts. Additionally, the relatively small sample size of participants in both rounds of the survey might restrict the applicability of the results. Upcoming studies may benefit from a broader participant pool and more comprehensive access to specialists in the field.

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References

1. Apanaviciene R, Vanagas A, Fokaides PA. Smart Building Integration into a Smart City (SBISC): Development of a New Evaluation Framework. Energies. 2020; 13(9): 2190. doi: 10.3390/en13092190
2. José R, Rodrigues H. A Review on Key Innovation Challenges for Smart City Initiatives. Smart Cities. 2024; 7(1): 141-162.

doi: 10.3390/smartcities7010006
3. Oktaria D, Suhardi, Kurniawan NB. Smart city services: A systematic literature review. In: Proceedings of the 2017 International Conference on Information Technology Systems and Innovation (ICITSI). pp. 206-213. doi: 10.1109/icitsi.2017.8267944
4. Singh T, Solanki A, Sharma SK. Role of Smart Buildings in Smart City—Components, Technology, Indicators, Challenges, Future Research Opportunities. Digital Cities Roadmap. 2021; 449-476. doi: 10.1002/9781119792079.ch14
5. Kim H, Choi H, Kang H, et al. A systematic review of the smart energy conservation system: From smart homes to sustainable smart cities. Renewable and Sustainable Energy Reviews. 2021; 140: 110755. doi: 10.1016/j.rser.2021.110755
6. Apanaviciene R, Urbonas R, Fokaides PA. Smart Building Integration into a Smart City: Comparative Study of Real Estate Development. Sustainability. 2020; 12(22): 9376. doi: 10.3390/su12229376
7. Peráček T, Kaššaj M. Legal Easements as Enablers of Sustainable Land Use and Infrastructure Development in Smart Cities. Land. 2025; 14(4): 681. doi: 10.3390/land14040681
8. Funta R. Automated Driving and Data Protection: Some Remarks on Fundamental Rights and Privacy. Krytyka Prawa. 2021; 13(4). doi: 10.7206/kp.2080-1084.495
9. PD 8100:2015—Smart cities overview. Guide. Available online: https://landingpage.bsigroup.com/LandingPage/Standard?UPI=000000000030320302 (accessed on 29 September 2024).
10. Want to drive sustainability? Your data has the power. Available online: https://discover.aveva.com/paid-search-op-pi-new-sustainability/whitepaper-want-to-drive-sustainability-your-data-has-the-power?utm_term=smart%20city%20information&utm_campaign=G_S_A_EMEA_EU_Campaign_Solution_Operations_Operate-PI-New&utm_source=adwords&utm_medium=ppc&gad_source=1&gclid=CjwKCAjw9eO3BhBNEiwAoc0-jREqB_oJmcXDU2pQU4h5Z12uMYW_5vQnXQEg-09Hjdt-83sf3C2WCBoCQtEQAvD_BwE (accessed on 29 September 2024).
11. Khaoula E, Amine B, Mostafa B. Machine Learning and the Internet of Things for Smart Buildings: A state of the art survey. In: Proceedings of the 2022 2nd International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET). pp. 1-10. doi: 10.1109/iraset52964.2022.9738256
12. Hamid M, Belarbi M, Adda C, et al. Characterization and Analytical Evaluation Based on the 3- Layer Approach of Smart Buildings. In: Proceedings of the 2023 Fifth International Conference on Advances in Computational Tools for Engineering Applications (ACTEA). pp. 83-88. doi: 10.1109/actea58025.2023.10194127
13. Gunatilaka RN, Abdeen FN, Sepasgozar SME. Developing a Scoring System to Evaluate the Level of Smartness in Commercial Buildings: A Case of Sri Lanka. Buildings. 2021; 11(12): 644. doi: 10.3390/buildings11120644
14. Thanh TQ, Thinh VG. Research for building the smart university model at Thu Dau Mot University. Journal of Thu Dau Mot University. 2022; 63-74. doi: 10.37550/tdmu.ejs/2022.04.361
15. Sleem A, Elhenawy I. Survey of Artificial Intelligence of Things for Smart Buildings: A closer outlook. Journal of Intelligent Systems and Internet of Things. 2023; 8(2): 63-71. doi: 10.54216/jisiot.080206
16. Milošević MR, Milošević DM, Stević DM, et al. Interval Valued Pythagorean Fuzzy AHP Integrated Model in a Smartness Assessment Framework of Buildings. Axioms. 2023; 12(3): 286. doi: 10.3390/axioms12030286
17. Plienaitis G, Daukšys M, Demetriou E, et al. Evaluation of the Smart Readiness Indicator for Educational Buildings. Buildings. 2023; 13(4): 888. doi: 10.3390/buildings13040888
18. Wang WC, Dwijendra NKA, Sayed BT, et al. Internet of Things Energy Consumption Optimization in Buildings: A Step toward Sustainability. Sustainability. 2023; 15(8): 6475. doi: 10.3390/su15086475
19. El-Diraby T, Sobhkhiz S. The building as a platform. Buildings and Semantics. 2022; 201-221. doi: 10.1201/9781003204381-11
20. Fakhimi AH, Khani AH, Sardroud JM. Smart-city infrastructure components. In: Solving Urban Infrastructure Problems Using Smart City Technologies. Elsevier; 2021. pp. 17–54. doi: 10.1016/B978-0-12-816816-5.00002-4
21. Crooks A, Schechtner K, Dey AK, et al. Creating Smart Buildings and Cities. IEEE Pervasive Computing. 2017; 16(2): 23-25. doi: 10.1109/mprv.2017.23
22. Manville C, Cochrane G, Cave J, et all. Mapping Smart Cities in the EU. European Parliament; 2015. doi: 10.2861/3408
23. Obringer R, Nateghi R. What makes a city 'smart' in the Anthropocene? A critical review of smart cities under climate change. Sustainable Cities and Society. 2021; 75: 103278. doi: 10.1016/j.scs.2021.103278
24. Kim N, Yang S. Characteristics of Conceptually Related Smart Cities (CRSCs) Services from the Perspective of

Sustainability. Sustainability. 2021; 13(6): 3334. doi: 10.3390/su13063334
25. Al Dakheel J, Del Pero C, Aste N, et al. Smart buildings features and key performance indicators: A review. Sustainable Cities and Society. 2020; 61: 102328. doi: 10.1016/j.scs.2020.102328
26. Junior JAG, Souza MGZND, Gobbo SCDO. Barriers and challenges to smart buildings' concepts and technologies in Brazilian social housing projects. International Journal of Sustainable Real Estate and Construction Economics. 2017; 1(1): 31. doi: 10.1504/ijsrece.2017.084362
27. Radziejowska A, Sobotka B. Analysis of the Social Aspect of Smart Cities Development for the Example of Smart Sustainable Buildings. Energies. 2021; 14(14): 4330. doi: 10.3390/en14144330
28. Lilis G, Conus G, Asadi N, et al. Towards the next generation of intelligent building: An assessment study of current automation and future IoT based systems with a proposal for transitional design. Sustainable Cities and Society. 2017; 28: 473-481. doi: 10.1016/j.scs.2016.08.019
29. Vlachokostas C. Smart buildings need smart consumers: the meet-in-the middle approach towards sustainable management of energy sources. International Journal of Sustainable Energy. 2020; 39(7): 648-658. doi: 10.1080/14786451.2020.1746789
30. Morvaj B, Lugaric L, Krajcar S. Demonstrating smart buildings and smart grid features in a smart energy city. In: Proceedings of the 2011 3rd International Youth Conference on Energetics.
31. Angelidou M. Smart city policies: A spatial approach. Cities. 2014; 41: S3-S11. doi: 10.1016/j.cities.2014.06.007
32. Qolomany B, Al-Fuqaha A, Gupta A, et al. Leveraging Machine Learning and Big Data for Smart Buildings: A Comprehensive Survey. IEEE Access. 2019; 7: 90316-90356. doi: 10.1109/access.2019.2926642
33. Moreno MV, Zamora MA, Skarmeta AF. User-centric smart buildings for energy sustainable smart cities. Transactions on Emerging Telecommunications Technologies. 2013; 25(1): 41-55. doi: 10.1002/ett.2771
34. Asif M, Naeem G, Khalid M. Digitalization for sustainable buildings: Technologies, applications, potential, and challenges. Journal of Cleaner Production. 2024; 450: 141814. doi: 10.1016/j.jclepro.2024.141814
35. Chinchero HF, Alonso JM, Ortiz TH. LED lighting systems for smart buildings: a review. IET Smart Cities. 2020; 2(3): 126-134. doi: 10.1049/iet-smc.2020.0061
36. Altaf M, Alalaoul WS, Musarat MA, et al. Optimisation of energy and life cycle costs via building envelope: a BIM approaches. Environment, Development and Sustainability. 2023; 26(3): 7105-7128. doi: 10.1007/s10668-023-03001-w
37. Hakawati B, Mousa A, Draidi F. Smart energy management in residential buildings: the impact of knowledge and behavior. Scientific Reports. 2024; 14(1). doi: 10.1038/s41598-024-51638-y
38. To WM, Lee PKC, Lam KH. Building professionals' intention to use smart and sustainable building technologies – An empirical study. PLOS ONE. 2018; 13(8): e0201625. doi: 10.1371/journal.pone.0201625
39. Bhatt JG, Jani OK, Bhatt CB. Automation Based Smart Environment Resource Management in Smart Building of Smart City. In: Smart Environment for Smart Cities. Advances in 21st Century Human Settlements. Springer, Singapore; 2020. pp. 93–107. doi: 10.1007/978-981-13-6822-6_3
40. Volkov AA, Batov EI. Simulation of Building Operations for Calculating Building Intelligence Quotient. Procedia Engineering. 2015; 111: 845-848. doi: 10.1016/j.proeng.2015.07.156
41. Muñiz R, del Coso R, Nuño F, et al. Solar-Powered Smart Buildings: Integrated Energy Management Solution for IoT-Enabled Sustainability. Electronics. 2024; 13(2): 317. doi: 10.3390/electronics13020317
42. Ghaffarianhoseini A, AlWaer H, Ghaffarianhoseini A, et al. Intelligent or smart cities and buildings: a critical exposition and a way forward. Intelligent Buildings International. 2017; 10(2): 122-129. doi: 10.1080/17508975.2017.1394810
43. Le DN, Le Tuan L, Dang Tuan MN. Smart-building management system: An Internet-of-Things (IoT) application business model in Vietnam. Technological Forecasting and Social Change. 2019; 141: 22-35. doi: 10.1016/j.techfore.2019.01.002
44. Sinopoli J. What Is a Smart Building? In: Smart Building Systems for Architects, Owners and Builders. Elsevier; 2010. pp. 1–5. doi: 10.1016/B978-1-85617-653-8.00001-6
45. Risteska Stojkoska BL, Trivodaliev KV. A review of Internet of Things for smart home: Challenges and solutions. Journal of Cleaner Production. 2017; 140: 1454-1464. doi: 10.1016/j.jclepro.2016.10.006
46. Li H, Liu Y, Qin Z, et al. A Large-Scale Urban Vehicular Network Framework for IoT in Smart Cities. IEEE Access. 2019; 7: 74437-74449. doi: 10.1109/access.2019.2919544
47. Akram AS, Abbas S, Khan MA, et al. Smart Energy Management System Using Machine Learning. Computers, Materials & Continua. 2024; 78(1): 959-973. doi: 10.32604/cmc.2023.032216
48. Fernandez-Ares A, Garcia-Sanchez P, Arenas MG, et al. Detection and Analysis of Anomalies in People Density and

Mobility Through Wireless Smartphone Tracking. IEEE Access. 2020; 8: 54237-54253. doi: 10.1109/access.2020.2979367
49. Kim D, Yoon Y, Lee J, et al. Design and Implementation of Smart Buildings: A Review of Current Research Trend. Energies. 2022; 15(12): 4278. doi: 10.3390/en15124278
50. Treiblmaier H, Rejeb A, Strebinger A. Blockchain as a Driver for Smart City Development: Application Fields and a Comprehensive Research Agenda. Smart Cities. 2020; 3(3): 853-872. doi: 10.3390/smartcities3030044
51. Hoang TV. Impact of Integrated Artificial Intelligence and Internet of Things Technologies on Smart City Transformation. Journal of Technical Education Science. 2024; 19(1): 64-73. doi: 10.54644/jte.2024.1532
52. Liu Z, Chi Z, Osmani M, et al. Blockchain and Building Information Management (BIM) for Sustainable Building Development within the Context of Smart Cities. Sustainability. 2021; 13(4): 2090. doi: 10.3390/su13042090
53. Ha Q, Phung MD. IoT-enabled dependable control for solar energy harvesting in smart buildings. IET Smart Cities. 2019; 1(2): 61-70. doi: 10.1049/iet-smc.2019.0052
54. Oulefki A, Amira A, Kurugollu F, et al. Dataset of IoT-based energy and environmental parameters in a smart building infrastructure. Data in Brief. 2024; 56: 110769. doi: 10.1016/j.dib.2024.110769
55. Metallidou CK, Psannis KE, Egyptiadou EA. Energy Efficiency in Smart Buildings: IoT Approaches. IEEE Access. 2020; 8: 63679-63699. doi: 10.1109/access.2020.2984461
56. Nirmala P, Ramesh S, Tamilselvi M, et al. An Artificial Intelligence enabled Smart Industrial Automation System based on Internet of Things Assistance. In: Proceedings of the 2022 International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI). pp. 1-6. doi: 10.1109/accai53970.2022.9752651
57. Shah S, Iqbal M, Aziz Z, et al. The Role of Machine Learning and the Internet of Things in Smart Buildings for Energy Efficiency. Applied Sciences. 2022; 12(15): 7882. doi: 10.3390/app12157882
58. Vijayan DS, Rose AL, Arvindan S, et al. Automation systems in smart buildings: a review. J Ambient Intell Humaniz Comput. 2020; 1–13. doi: 10.1007/S12652-020-02666-9/METRICS
59. Sadowski S, Spachos P. Comparison of RSSI-Based Indoor Localization for Smart Buildings with Internet of Things. In: Proceedings of the 2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON). doi: 10.1109/iemcon.2018.8614863
60. Krishnan P, Prabu AV, Loganathan S, et al. Analyzing and Managing Various Energy-Related Environmental Factors for Providing Personalized IoT Services for Smart Buildings in Smart Environment. Sustainability. 2023; 15(8): 6548. doi: 10.3390/su15086548
61. Xu W, Zhang J, Kim JY, et al. The Design, Implementation, and Deployment of a Smart Lighting System for Smart Buildings. IEEE Internet of Things Journal. 2019; 6(4): 7266-7281. doi: 10.1109/jiot.2019.2915952
62. Krishnan S, Anjana MS, Rao SN. Security Considerations for IoT in Smart Buildings. In: Proceedings of the 2017 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC). pp. 1-4. doi: 10.1109/iccic.2017.8524450
63. Ciholas P, Lennie A, Sadigova P, Such JM. The Security of Smart Buildings: a Systematic Literature Review. arXiv. 2019; arXiv:1901.05837.
64. Edirisinghe R. Digital skin of the construction site. Engineering, Construction and Architectural Management. 2018; 26(2): 184-223. doi: 10.1108/ecam-04-2017-0066
65. Sodhro AH, Pirbhulal S, Luo Z, et al. Towards an optimal resource management for IoT based Green and sustainable smart cities. Journal of Cleaner Production. 2019; 220: 1167-1179. doi: 10.1016/j.jclepro.2019.01.188
66. Esmaeilpoorarabi N, Yigitcanlar T, Guaralda M, et al. Evaluating place quality in innovation districts: A Delphic hierarchy process approach. Land Use Policy. 2018; 76: 471-486. doi: 10.1016/j.landusepol.2018.02.027
67. Grime MM, Wright G. Delphi Method. In: Wiley StatsRef: Statistics Reference Online. Wiley; 2016. pp. 1–6. doi: 10.1002/9781118445112.stat07879
68. Nusir M, Alshirah M, ALMashaqbeh S, et al. The Delphi method to analyze the expert views on possible futures of the smart city adoption and development in developing countries: the case of Jordan. PeerJ Computer Science. 2024; 10: e2061. doi: 10.7717/peerj-cs.2061
69. Shahrabani MMN, Apanaviciene R. An AI-Based Evaluation Framework for Smart Building Integration into Smart City. Sustainability (Switzerland). 2024; 16(18): 8032. doi: 10.3390/SU16188032/S1
70. Li L, Taeihagh A, Tan SY. What factors drive policy transfer in smart city development? Insights from a Delphi study. Sustainable Cities and Society. 2022; 84: 104008. doi: 10.1016/j.scs.2022.104008

71. Alamoudi AK, Abidoye RB, Lam TYM. Implementing Smart Sustainable Cities in Saudi Arabia: A Framework for Citizens' Participation towards SAUDI VISION 2030. Sustainability. 2023; 15(8): 6648. doi: 10.3390/su15086648
72. Tian J. Analysis of Influencing Factors of Residents' Happiness in Smart Cities based on Principal Component Analysis. Journal of Education and Educational Research. 2024; 8(3): 61-69. doi: 10.54097/nh5jes24
73. Mat Roni S, Djajadikerta HG. Data Analysis with SPSS for Survey-Based Research. Springer Singapore; 2021. doi: 10.1007/978-981-16-0193-4
74. Alves AP, Milani AMP, Manssour IH. Visual Analytics System for Energy Data in Smart Cities and Buildings. In: Proceedings of the 2020 IEEE International Smart Cities Conference (ISC2). pp. 1-8. doi: 10.1109/isc251055.2020.9239006
75. Izatullayeva B, Turkeyeva E, Kulbayeva A. Improving the Importance of a Smart city in Achieving a Sustainable Tourism sector. Eurasian Science Review An International Peer-Reviewed Multidisciplinary Journal. 2024; 2(2): 76-86. doi: 10.63034/esr-57
76. Spieldenner D, Spieldenner T. A Smart Integration Layer for Smart City Business Applications. In: Proceedings of the 2020 4th International Conference on Smart Grid and Smart Cities (ICSGSC). pp. 129-135. doi: 10.1109/icsgsc50906.2020.9248545
77. Kousis A, Tjortjis C. Data Mining Algorithms for Smart Cities: A Bibliometric Analysis. Algorithms. 2021; 14(8): 242. doi: 10.3390/a14080242
78. Yuan P. Smart Grid Renewable Energy Configuration Decision Model Based on Multi-Objective Optimization. International Journal of Computer Science and Information Technology. 2024; 3(2): 157-166. doi: 10.62051/ijcsit.v3n2.18
79. Cardoso PCN, Schettino S, Minette LJ, et al. Paradigms of environmental sustainability in photovoltaic energy generation. Delos: Desarrollo Local Sostenible. 2024; 17(52): e1256. doi: 10.55905/rdelosv17.n52-002
80. Kumar R, Gaur ES, Raut AB, Howard E. Machine Learning-Driven Energy Harvesting and Storage System Design for IoT Applications in Smart Buildings. Tuijin Jishu/Journal of Propulsion Technology. 2024; 45(02): 2700-2712. doi: 10.52783/tjjpt.v45.i02.6318
81. Neupane C, Wibowo S, Grandhi S, et al. A Trust-Based Model for the Adoption of Smart City Technologies in Australian Regional Cities. Sustainability. 2021; 13(16): 9316. doi: 10.3390/su13169316
82. Shin SY, Kim D, Chun SA. Digital Divide in Advanced Smart City Innovations. Sustainability. 2021; 13(7): 4076. doi: 10.3390/su13074076
83. Alhalafi N, Veeraraghavan P. Exploring the Challenges and Issues in Adopting Cybersecurity in Saudi Smart Cities: Conceptualization of the Cybersecurity-Based UTAUT Model. Smart Cities. 2023; 6(3): 1523-1544. doi: 10.3390/smartcities6030072
84. Bhuvana J, Kant Gautam C, Yadav DK, et al. Utilizing Artificial Intelligence and IoT for Enhanced Renewable Energy Management in Smart Cities. E3S Web of Conferences. 2024; 540: 13009. doi: 10.1051/e3sconf/202454013009
85. Shu M, Wu S, Wu T, et al. Efficient energy consumption system using heuristic renewable demand energy optimization in smart city. Computational Intelligence. 2020; 38(3): 784-800. doi: 10.1111/coin.12412
86. Zakzak L. Citizen-centric Smart City Development. In: Proceedings of the 20th Annual International Conference on Digital Government Research. 2019. pp. 141-147. doi: 10.1145/3325112.3325236
87. Tasențe T, Stan MI. Citizen-Centric Smart Cities: Empowering Public Administration through Social Media and Citizen Engagement. Croatian and Comparative Public Administration. 2024; 23(4): 529-558. doi: 10.31297/hkju.23.4.5
88. Bandauko E, Nutifafa Arku R. A critical analysis of 'smart cities' as an urban development strategy in Africa. International Planning Studies. 2022; 28(1): 69-86. doi: 10.1080/13563475.2022.2137112
89. AL-Dabbagh R. Dubai, the sustainable, smart city. Renewable Energy and Environmental Sustainability. 2022; 7: 3. doi: 10.1051/rees/2021049
90. Carvalho R. Urban Planning, Nature-Based Solutions and Local Sustainability. In: Resilience and Reform: Administrative Law and Public Policy in a Changing World, ADJURIS. International Academic Publisher; 2024. pp. 161–181. doi: 10.62768/ADJURIS/2024/3/11
91. Anwar MR, Sakti LD. Integrating Artificial Intelligence and Environmental Science for Sustainable Urban Planning. IAIC Transactions on Sustainable Digital Innovation (ITSDI). 2024; 5(2): 179-191. doi: 10.34306/itsdi.v5i2.666
92. Habib A, Alsmadi D, Prybutok VR. Factors that determine residents' acceptance of smart city technologies. Behaviour & Information Technology. 2019; 39(6): 610-623. doi: 10.1080/0144929x.2019.1693629
93. Waclawek T, Fiedler A, Schütz M, et al. Crowd-counting technology within the Smart City context: understanding, trust, and

acceptance. Frontiers in Psychology. 2024; 15. doi: 10.3389/fpsyg.2024.1423837
94. Tekin H, Dikmen I. Inclusive Smart Cities: An Exploratory Study on the London Smart City Strategy. Buildings. 2024; 14(2): 485. doi: 10.3390/buildings14020485
95. Kamvysi K, Tsironis LK, Gotzamani K. An integrated QFD framework for smart city strategy development. TQM Journal. 2024. doi: 10.1108/TQM-07-2023-0223/FULL/XML