Effects of IOT Services and Urban Development to Achieve Urban Sustainability: Role of Urban Planner Knowledge

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Abstract
Urban development has remained a central focus in the Saudi Arabia since past few decades. In the pursuit of sustainable growth and improved energy utilization, it becomes essential to investigate the key contributors to these objectives. This study investigates the influence of IoT services, environmental concern, and infrastructure and urban development on urban liveability, with a further examination of their impact on smart urban sustainability and energy efficiency. The mediating role of urban liveability is also assessed. This study adopted quantitative research approach with Convience sampling method to reach the respondents and for questionnaire distribution. The gathered data was examined using SEM through smart PLS 4. Findings indicate that IoT services, environmental concern, and infrastructure and urban development significantly enhance urban liveability. Furthermore, urban liveability demonstrates a meaningful impact on both smart urban sustainability and energy efficiency. The mediating role of urban liveability is also validated. These insights offer theoretical and managerial implications for urban planners and policymakers in the Saudi Arabian context.

Keywords: Urban Development, Urban Liveability, Energy Efficiency, Smart Sustainability, Infrastructure and Urban development.

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INTRODUCTION

Urban regions serve as key drivers of a nation's infrastructure expansion, social advancement, and economic progress [1]. For the economic growth of any country, infrastructure development remains essential. It enhances transportation systems, thereby facilitating the movement of goods and services. In the long run, such development contributes significantly to boosting the national economy [2]. Furthermore, urban development fosters improved operational environments for businesses, leading to job creation and increased investment. As urbanization rises, collaboration between the private and public sectors on large-scale infrastructure projects becomes essential to ensure long-term adaptability and societal resilience. Investment in smart infrastructure is equally crucial for building a prosperous, connected, and competitive future [3].

Sustainable urban development holds significance due to its long-term benefits for a country. These advantages include improved quality of life, increased economic revenue, and a reduced environmental footprint [4]. Governments can generate employment by investing in various sustainability initiatives. Sustainable development contributes to economic growth while also leading to reductions in population pressures, waste generation, and energy consumption [5]. Communities actively participate in achieving sustainable development goals and transforming conventional cities into smart, innovation-driven urban centers. These cities primarily depend on technology-based infrastructure, including the Internet of Things (IoT), 5G networks, and high-speed internet. Such infrastructure plays a vital role in collecting and analyzing data to enhance the quality of urban life [6].

Energy efficiency plays a crucial role in ensuring sustainable development [7]. It is essential for countries to secure access to sustainable energy resources to support their long-term development. A key challenge lies in ensuring the availability of these resources over extended periods and at an affordable cost. Sustainable development can be achieved by utilizing energy in ways that minimize environmental harm while maximizing overall benefits [8]. Global energy demand has risen due to improving living standards, rapid technological advancements, and high population growth rates. The energy sector serves as a critical input for all segments of the economy [9]. Thus, consistent and stable energy policy is vital for sustainable development.

Cities worldwide are facing unprecedented challenges due to rapid urbanization. These issues include environmental degradation, depletion of natural resources, and increased overcrowding in urban areas [10]. With the expansion of urban areas, there is an urgent need for innovative solutions to improve sustainability and urban infrastructure. In this context, the Internet of Things (IoT) emerges as a key technology offering a framework for cities to address these challenges effectively [11]. By integrating Internet of Things (IoT)-based systems and devices into urban environments, cities can progress toward sustainable development. IoT is a powerful tool with the potential to transform urban planning by fostering more liveable and responsive urban spaces [12], sustainable and efficient cities. By utilizing data generated from connected devices, cities can optimize resource management, enhance citizens' quality of life, improve public services, and increase overall service efficiency [13].

The parameters of natural environment must be considered to improve urban planning and effective management or urban areas [14]. Urban planning plays a critical role in shaping environmental policies that guide the development of communities and cities. As the world confronts challenges such as environmental degradation, sustainability, and climate change, the significance of urban planning in addressing these issues cannot be overstated [15]. By integrating urban planning with environmental considerations, cities can foster more equitable, sustainable, and healthier environments. The primary goal of environmental planning is to create a win-win scenario for both the environment and society [16]. Through successful planning regarding environment, society can win by using land in effective way for production purpose, whereas, environment can win by sustaining itself for upcoming generation.

The concept of urban liveability is gaining prominence with the rapid acceleration of urbanization. Existing research highlights liveability as a central objective within urban design practices [17]. Therefore, urban liveability is a vital concept within the domains of urban development, planning, and research. It emphasizes the notion of "people-friendliness." A liveable city is one that fosters a sense of belonging, strengthens community ties, offers economic opportunities, and ensures a high quality of life. Such urban settings are characterized by physical infrastructure and development that contribute to residents' well-being. Enhancing urban liveability can lead to greater overall satisfaction, improved social cohesion, and better public health outcomes [18]. Urban liveability represents a holistic approach to development, addressing the interconnectedness of environmental, economic, and social dimensions.

As the Kingdom of Saudi Arabia experiences rapid urbanization, achieving urban liveability becomes essential for promoting energy efficiency and advancing smart urban sustainability. Accordingly, the present study investigates the impact of IoT services, energy efficiency, and infrastructure and urban development on urban liveability, and subsequently, on energy efficiency and smart urban sustainability.

LITERATURE REVIEW

Urban Liveability; Energy Efficiency

In literature, energy efficiency is referred to as practices and technology that minimize the amount of required energy to power industries, businesses, and homes [19]. It involves promoting the usage of energy sources that are renewable, reducing energy waste, and optimizing consumption of energy. Energy efficiency is important to minimize emissions of greenhouse gases, ensure sustainability, and mitigate climate change. Energy efficiency is one of the integral parts of sustainable development in the process of urbanization [20].

Academics are always interested in assessing the effect of urban liveability on energy efficiency [21]. There exists a close link between urban liveability and energy efficiency in the context of urban planning. Quality of life can be improved and consumption of energy can be reduced with effective and efficient urban planning. In the long run, it helps in mitigating the negative effect of urbanization on the environment [22]. Urban liveability has a significant effect on energy efficiency [23]. The reliance on personal vehicles is reduced in cities that are well-developed, have well-planned infrastructure, and access to public transportation. This situation leads to lower personal vehicle use and efficient consumption of energy. Efficient urbanization also helps in minimizing the usage of energy for cooling and heating in buildings using improved renewable energy sources [24]. There is a need for efficient urban planning to achieve energy efficiency through urban liveability. Hence, results of Yu, and Luo[25] revealed that urban liveability has a positive significant effect on energy efficiency.

H1: Urban Liveability is significantly related to energy efficiency.

Urban Liveability; Smart Urban Sustainability

Scholars have defined urban sustainability as city's capability in terms of successful operations across different domains including environmental domain, social domain and economic domain [26]. Smart urban technologies can be used to achieve urban sustainability [27]. Smart urban technologies are advanced communication and digital technologies that are used in a city. These technologies are important components of smart city projects that are adopted for the purpose of innovation to manage the cities [28].

Urban liveability in literature is defined as the level to which a city can provide a satisfying and decent life for its citizens on the basis of various aspects of their living conditions and well-being [29]. It is very important to understand liveability to design cities that can address the needs of citizens immediately and provide long-term sustainability. The conceptual foundation of urban liveability is developed on four different dimensions such as safety, health, amenity, and convenience [21]. A high level of urban liveability shows that residents in the city have good social interaction and enjoy convenient and safe environments.

The concepts of sustainability and liveability are discussed in literature as buzzwords in the research of urban planning. The term liveability is dependent upon the rules of sustainable and smart cities [18]. Thus, it is sensitive to the protection of resources and nature. Smart sustainable cities play a critical role in providing economically resilient and socially and environmentally healthy habitats for their citizens. The key factor is that usage of resources for the upcoming generation is not compromised [30]. The concepts of urban liveability and urban sustainability are linked to each other, as the main focus of both concepts is to develop cities that are environmentally responsible and enjoyable for future and current generations.

The concept of liveability focuses on the quality of life within the city, whereas the emphasis of sustainability is on its resource management and long-term environmental management [31]. These concepts are interlinked because smart sustainability cannot be achieved without a city's liveability. Moreover, the quality of life within the city can be improved as a result of sustainable efforts. The study by Abdelkarim, *et al.*[32] determined that through the improvement of liveability via involvement in urban facility management, smart sustainability will be supported as well. In other words, liveability has a significant positive effect on smart sustainability. Likewise, scholars also revealed that urban liveability is one of the important factors to improve sustainable development [33].

H2: Urban Liveability is significantly related to Smart Urban Sustainability.

Infrastructure & urban development and Urban Liveability

For smart urban growth, the major concern for planners is infrastructure development [34]. The factors of infrastructure development improve smart urban growth and also serve as the key factor of services namely water, communication, energy, and transportation systems. From the perspective of smart cities, development of infrastructure not only involves the development of physical assets, but also the integration of modern technology with the purpose of enabling efficient and smarter urban management [35]. Careful planning is required to ensure that the required or developed infrastructure is sustainable and has the capacity to support the advancement of technology in the future [36]. For the alignment of infrastructure development with the objectives of the city, knowledge of urban planning is a basic requirement. The vitality of urban infrastructure can be viewed from the perspectives of economy, society, and environment. Urban infrastructure can have a significant effect on residents' quality of life, security, and health. It is not possible for a country to function without basic infrastructure despite its geographical location, type, and size [28].

From the aspects of amenity, it is emphasized that residents feel enjoyment and comfort as a result of adequate spaces and infrastructure [37]. High liveability is indicated in areas that have sufficient spaces and infrastructure. Residents do not like to live in areas that do not have essential urban assets. Based on different levels of liveability, a city can be segmented into different tiers of liveability. With the help of adequate infrastructure, a city can be transformed into a climate-resilient, liveable, well-functioning, and productive urban area. The safety, timeliness, flexibility, relevance, and reliability of urban infrastructure have a significant positive effect on urban liveability [21]. Urban infrastructure provides a conducive environment during urban development, as a result of which it is possible for an economy to grow and the standard of living of the residents living in cities is improved as well. In turn, this leads to an improved transport system, quality of life, and better housing [38]. Thus, infrastructure and urban development have a positive significant effect on urban liveability [21].

H3: Infrastructure & urban development is significantly related to Urban Liveability.

Mediation role of liveability between Infrastructure & urban development and energy efficiency; smart urban sustainability

Infrastructure and urban development play a very important role in promoting sustainable planning through urban liveability. Thoughtful development and quality infrastructure encourage the efficient usage of energy by enhancing liveability. As a result, a higher level of liveability reduces the demand for energy [39]. Therefore, liveability develops links among development strategies and energy efficiency.

Moreover, infrastructure and urban development play a key role in meeting the needs of residents by impacting the environment at the minimum level. Liveable urban development prioritizes efficient services, mobility, and green spaces, leading towards sustainable outcomes [40]. This balance improves quality of life and enhances environmental responsibility [41]. According to Preacher, *et al.*[42], there are two conditions under which a variable can be considered a mediator: i.e., there must be a significant relationship between the IV and the mediator (as condition 'a'), whereas the mediating variable should have a significant effect on the DV (as condition 'b'). From the perspective of the present study, infrastructure and urban development have a significant effect on urban liveability [21] meeting condition 'a', and urban liveability has a positive effect on energy efficiency [25] and smart city sustainability [33], meeting condition "b". Thus, we hypothesise that.

H4: Urban Liveability Significantly mediates between Infrastructure & urban development and energy efficiency.
H5: Urban Liveability Significantly mediates between Infrastructure & urban development and smart urban sustainability.

IOT Services and Urban Liveability

A number of different services are provided by the IoT system, including device discovery services, data publishing services, data controlling services, and data monitoring services. The present diffusion of IoT technologies is opening the doors to a number of new possibilities [43]. It plays a very important role in developing and planning smart cities. In literature, IoT is defined as the integration of ICT and IoT for the management of a city with the aim to address the exponential growth of population and urbanization, having a significant effect on the quality of life of residents [44]. The Internet of Things develops the foundation for the initiatives of a smart city, enabling urban environments to become more responsive, sustainable, and efficient to the needs of residents and their liveability. The integration of IoT enhances the efficiency of urban operations and also develops the way for a liveable urban environment for the residents [45].

The IoT-based solutions in the areas of urbanization contribute significantly to the well-being of society, making a city liveable [46]. Smart cities leverage IoT's data-driven capability, technology, and interconnectedness to develop a responsive, efficient, and intelligent urban environment to enhance quality of life and sustainability [47]. Cities use IoT sensors with the purpose of collecting real-time data regarding traffic flow, energy consumption, and air quality that are frequently used for resource allocation and urban planning. Cities get help from urban IoT solutions to improve operational efficiency, allocation of resources, and recognition of urban trends. In other words, IoT services have a significant effect on liveability [45,48] as they improve the efficiency of resources, public safety, transportation, and management of infrastructure.

H6: IOT Services is significantly related to Urban Liveability.

Mediation role of liveability between IOT Services and energy efficiency; smart urban sustainability

Urban liveability develops alignment between human-developed urban design and technological advancements. IoT systems, including energy monitoring, traffic control, and smart lighting, improve operational efficiency [49]. When the IoT system is integrated with urban liveable planning, energy usage is optimized, creating safety and comfort for the citizens. It is ensured through liveability that urban needs are addressed by IoT solutions, improving quality of life and sustainability [45]. Therefore, the relationship between IoT and energy efficiency is bridged by urban liveability.

On the other hand, quality of life is improved and sustained by IoT services. IoT systems play an important role in achieving human-developed goals, ensuring efficient and sustained usage of resources. IoT also helps in the sustainability of the urban environment as it prioritizes resilience and the well-being of the citizens [50]. According to Preacher*, et al.*[42], there are two conditions that need to be met for a variable to be considered a mediating variable. As condition 'a', there must be a relationship between the IV and the mediating variable. In this study, IoT systems have a significant effect on urban liveability [45], meeting condition 'a'. On the other hand, urban liveability has a significant effect on energy efficiency [25] and smart urban sustainability [33]. Thus, we hypothesise that:

H7: Urban Liveability Significantly mediates between IOT Services and energy efficiency.
H8: Urban Liveability Significantly mediates between IOT Services and smart urban sustainability.

Environmental concerns and Urban Liveability

Environmental concern is explained as the awareness of the individual regarding the environment being threatened by pollution and resource depletion [51]. In literature, environmental concern is referred to as a specific attitude that has a direct effect on intention and attitude, impacting value orientation and general intention. Urban liveability is significantly affected by environmental concerns through exposure to extreme weather events, access to green spaces, and water and air quality. The negative consequences can lead to displacement of residents, increased health risks, and reduced quality of life [52]. The negative impact of the environment poses a real threat to urban liveability [53].

Promotion of urban liveability with socio-economic and environmental concern is very important for urban managers and researchers. Urban ecology is directly threatened by climate change with increased risks of floods and heat. All these factors have a negative impact on urban liveability [54]. In the context of China, Shi*, et al.*[24] revealed that multiple environmental concerns have a significant effect on liveability.

H9: Environmental concern is significantly related to Urban Liveability.

Mediation role of liveability between Environmental concerns and energy efficiency; smart urban sustainability

The relationship between environmental concern and energy efficiency is mediated by urban liveability, as this factor promotes public transport, green spaces, and sustainable infrastructure. Energy demand and pollution are reduced in a liveable city with the help of smart planning [55]. As a result, ecological balance and quality of life are improved. Therefore, urban planning bridges the relationship between environmental concerns and energy efficiency.

Additionally, urban liveability also has the potential role of mediator between environmental concerns and smart urban sustainability. Studies mention that public health and green design are improved as a result of environmental concerns and liveability planning [56]. Moreover, alignment is developed with sustainable practices, smart technology, and human needs, improving the quality of life of the citizens by preserving resources. Preacher, *et al.*[42] stated that a variable can be considered a mediator if the IV has a significant effect on the mediator, and the mediator later has a significant effect on the DV. In the present study, environmental concern has a significant effect on urban liveability [24], meeting condition 'a'. Whereas, urban liveability has a positive significant effect on energy efficiency and smart urban sustainability [25,33], meeting condition "b". Thus, we propose that

H10: Urban Liveability Significantly mediates between Environmental concerns and energy efficiency.
H11: Urban Liveability Significantly mediates between Environmental concerns and smart urban sustainability.

Based on the above literature review and discussion, this study proposed the following framework (Figure 1).

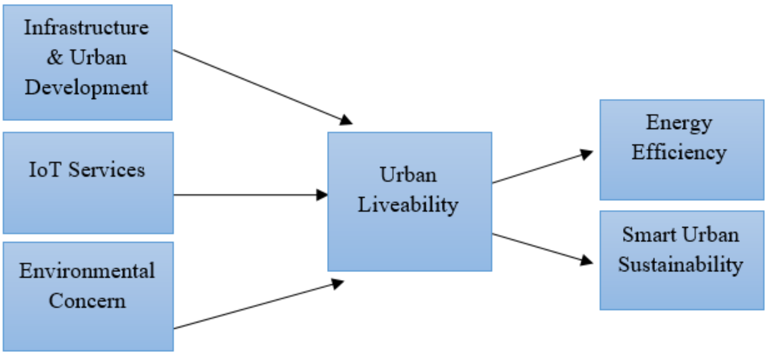

Figure 1: Theoretical Framework of Research

RESEARCH METHODOLOGY

Keeping in view the objectives of the study, this research used a quantitative survey with a descriptive approach. Auliya, *et al.*[57] used a quantitative method that focuses on numbers and uses statistical methods for analysis. These numerical figures are used for the significance of the hypothesis as well. In this study, a convenience sampling approach was used to collect the data. Data was collected from the citizens of the city of Riyadh, Saudi Arabia. The questionnaire was developed in two sections to collect data from the respondents. The developed questionnaire was distributed among 325 residents of the city of Riyadh. This study received 267 usable questionnaires from the respondents, having a response rate of 82.15%.

The independent variables of the study are infrastructure and urban development, IoT services, and environmental concern. The mediating variable is urban liveability, and the dependent variables include energy efficiency and smart urban sustainability. In this study, infrastructure and urban development were assessed using six items from Feng, *et al.*[58]; IoT was assessed using 4 items adopted from Liu, *et al.*[59]; environmental concern was examined using 4 items adapted from Feng, *et al.*[58]; urban liveability was examined through four instruments taken from Nicolas, *et al.*[47]et al; whereas five items from Wang, *et al.*[60] were used to examine energy efficiency in this research; and six items from Agboola, *et al.*[28] were adapted to examine smart urban sustainability.

The collected data from the respondents were examined using the SEM-PLS analysis technique through Smart PLS version 4. According to Hair Jr, *et al.*[61] SEM-PLS is always a preferred choice, especially to intervene in model analysis. The present study used this software and method because of their ability to test and interpret the data efficiently. Furthermore, Smart PLS 4 has the ability to handle complex models [62]. The present study also has a complex model, having three independent variables, one mediating variable, and two dependent variables.

RESULTS

In this study, demographic data was analyzed using SPSS version 26. Table 1 of the study shows the demographic analysis showing age, gender, and marital status of the respondents. The figures mentioned in table 1 shows that more than 73% of the respondents were man and 26.79% of the respondents were females. In terms of age, 21.27% of the respondents had the age between 18 to 30 years, 32.43% has the age between 31 to 40 years, 26.02% had the age between 41 to 50 years and remaining 20.08% were more than 50 years of age.

Table 1: Demographic analysis

	Category	%
Gender	Men	73.21
	Women	26.79
Age	18-30	21.27%
	31-40	32.43%
	41-50	26.02%
	50 above	20.08
Marital Status	Married	79.01
	Not married	20.09

Analysis of SEM through Smart PLS 4 is based on two stages namely measurement model. This study performed measurement model to examine factor loading, discriminant validity and convergent validity (Table 2). At the initial stage Cronbach Alpha, AVE and CR were examined to assess internal consistency and validity.

Table 2: validity and consistency

Constructs		Loading	α	CR	AVE
Energy Efficiency	EE1	0.954	0.937	0.953	0.803
	EE2	0.964			
	EE3	0.744			
	EE4	0.924			
	EE5	0.877			
Environmental Control	ENVC1	0.857	0.877	0.914	0.727
	ENVC2	0.803			
	ENVC3	0.886			
	ENVC4	0.863			
IoT Service	IOT1	0.840	0.838	0.902	0.755
	IOT2	0.863			
	IOT3	0.902			
Infrastructure & Urban Development	IUD1	0.712	0.796	0.842	0.520
	IUD2	0.733			
	IUD3	0.576			
	IUD4	0.749			
	IUD5	0.814			
Smart Urban Sustainability	SS1	0.794	0.873	0.913	0.725
	SS2	0.914			
	SS3	0.878			
	SS4	0.813			
Urban Liveability	UL1	0.820	0.881	0.918	0.738
	UL2	0.876			
	UL3	0.914			
	UL4	0.823			

Factor loading

Outer loading outer loading is the test that is used to measure the correlation among the variables. Higher loading shows high level of closeness among the variables. According to [62,]Haji-Othman, and Yusuff[63] the items having loading of more than 0.40 is acceptable. Table 2 shows that all items that are retained in the present research have the factor loading of more than 0.40.

Reliability and convergent validity

Reliability is measured using PLS-SEM through composite reliability and Cronbach Alpha. Cronbach Alpha examines the lower limit of the variables reliability whereas composite reliability has the ability to examine higher estimates that are suitable. According to Hair Jr, *et al.*[64], the CR and Cronbach Alpha values of more than 0.70 are acceptable. The values of Table 2 show that these benchmarks are fulfilled in this study. According to Fornell, and

Larcker[65], the values of AVE for a variable should be more than 0.50 to establish convergent validity. The values of AVE in table 2 shows that all values are above 0.50, establishing convergent validity.

Discriminant Validity (HTMT)

Discriminant validity tests examines the difference among the constructs [57]. According to Henseler, *et al.*[66] the values of HTMT should be less than 0.85 to establish discriminant validity. Statistical results of Table 3 shows that all values of HTMT are less than 0.85, establishing discriminant validity. At this stage, measurement model is successfully evaluated. Later, R square is assessed and proposed hypothesis are examined at structural model stage. Bootstrapping procedure is used to examine the significance of hypothesis.

Table 3: Discriminant validity

	EE	ENVC	IOT	IUD	SS	UL
EE						
ENVC	0.777					
IOT	0.738	0.730				
IUD	0.666	0.806	0.684			
SS	0.847	0.818	0.786	0.887		
UL	0.842	0.801	0.751	0.651	0.826	

R square

The statistical test of R square explain how far independent variable has impact on dependent variables [67].Whereas, Sarstedt, *et al.*[68] mentioned that value of R square less than 0.25 is considered as very weak, whereas, between 0.25 and 0.50 is considered as weak, between 0.50 and 0.75 is considered moderate, and more than 0.75 is considered as fair. Table 4 shows that all values of R square are moderate.

Table 4: R square

	R-square
EE	0.634
SS	0.551
UL	0.594

Hypothesis Testing

Table 5 and Figure 2 represents the results of the proposed direct and indirect hypotheses. The results show that urban liveability has a positive significant effect on energy efficiency. Thus, H1 is supported (t=22.261, p=0.000). The results also show that urban liveability has a positive significant effect on smart urban sustainability, supporting H2 (t=20.204, p=0.000). Likewise, H3 of the study is also supported, showing that infrastructure and urban development have a positive effect on urban liveability (t=2.210, p=0.014). The statistical findings also support the notion that IoT services have a positive effect on urban liveability (t=4.103, p=0.000), supporting H6. In the end, the results also support the hypothesis stating that environmental concern has a significant effect on urban liveability (t=4.103, p=0.000).

Table 5: Relationships

HYP		B	SD	T stats	P Stats	Decision
H1	UL -> EE	0.796	0.036	22.261	0.000	Supported
H2	UL -> SS	0.742	0.037	20.204	0.000	Supported
H3	IUD -> UL	0.164	0.074	2.210	0.014	Supported
H4	IUD -> UL -> EE	0.130	0.061	2.123	0.017	Supported
H5	IUD -> UL -> SS	0.122	0.058	2.101	0.018	Supported
H6	IOT -> UL	0.292	0.071	4.103	0.000	Supported
H7	IOT -> UL -> EE	0.232	0.057	4.097	0.000	Supported
H8	IOT -> UL -> SS	0.217	0.053	4.061	0.000	Supported
H9	ENVC -> UL	0.411	0.088	4.669	0.000	Supported
H10	ENVC -> UL -> EE	0.327	0.071	4.634	0.000	Supported
H11	ENVC -> UL -> SS	0.305	0.066	4.643	0.000	Supported

Table 5 of the study also represents the results showing the mediating role of urban liveability. The statistical figures show that the mediating effect of urban liveability is confirmed between infrastructure and urban energy efficiency (t=2.123, p=0.017), between infrastructure and urban development and smart urban sustainability (t=2.101, p=0.018), between IoT services and energy efficiency (t=4.097, p=0.000), between IoT services and smart urban sustainability (t=4.061, p=0.000), between environmental control and energy efficiency (t=4.634, p=0.000), and between environmental control and smart urban sustainability (t=4.643, p=0.000). Therefore, H4, H5, H7, H8, H10, and H11 are supported in the present study as well.

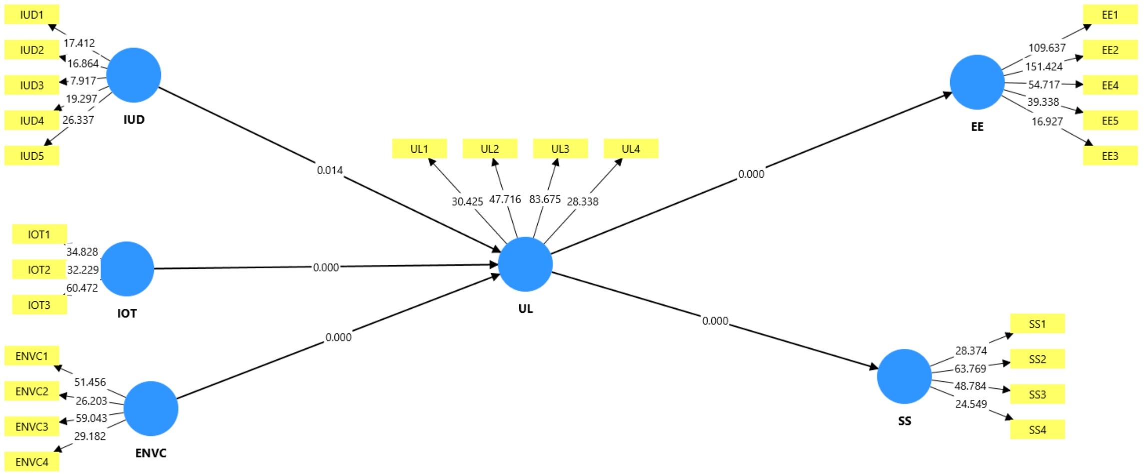

Figure 2: Structural Model

DISCUSSION

The Kingdom of Saudi Arabia is among the fastest-growing countries globally in terms of economic and urban development. As a result of rapid population growth, urban development in KSA has become important. From this perspective, enhancing urban liveability is essential to impact smart urban sustainability and energy efficiency. In this context, it is important to explore the factors that can influence urban liveability and later impact energy efficiency and urban and infrastructure development. Therefore, this study examined the effects of environmental control, IoT services, and infrastructure and urban development on energy efficiency and smart urban sustainability through the mediation of urban liveability.

The results of the study show that urban liveability has a positive effect on energy efficiency. The respondents of the study are of the view that excessive energy consumption is reduced because of an accessible, compact, and well-planned urban environment. Some of the respondents mentioned that the liveability of the city prioritizes green spaces, public transportation, and walkability. All these factors combine to minimize the need for private transportation by reducing energy usage in terms of transportation. On the other hand, respondents of the study mentioned that the main focus of liveability is on building designs that are energy-efficient and smart infrastructure. High quality of life is maintained for the respondents in this situation as resources are optimized. Respondents pointed out that they tend to save energy in such an environment as a result of environmental awareness. The focus of urban liveability is also on efficient public services, which also has a major contribution to energy consumption. In past Shi, *et al.*[24] also revealed same findings in their studies,

The statistical figures also supported the hypothesis that urban liveability has a positive significant effect on smart urban sustainability. The residents of Riyadh mentioned that they feel secure in the areas where they live. Moreover, the management of residents has provided them with a good quality of life, resulting in their happiness. Furthermore, the social services offered by the management are also affordable, leading to a situation where the respondents like to use these services. Some of the respondents mentioned that they have a feeling of public safety in the area as well. On the other hand, Saudi citizens may also believe that urban liveability plays a vital role in providing a better quality of life, as they have improved infrastructure. Moreover, smart technologies are also integrated into livable cities, reducing energy consumption and resulting in a reduced impact on the environment. All these factors may lead residents to adopt sustainable behavior by minimizing their dependency on private transportation along with using systems that are energy efficient. Balanced urban growth is a result of liveability. The findings of Abdelkarim, *et al.*[32] also revealed same findings in their study.

The results of the study also revealed that environmental control has a positive effect on urban liveability. Some of the respondents mentioned that Saudi Arabia is also experiencing climate change similar to other regions of the world. In this situation, urban liveability can be enhanced through environmental controls. They believe that effective environmental controls like sustainable waste management, temperature regulation, water management, and pollution management have a direct effect on the well-being, health, and comfort of the citizens. In the context of KSA, there is extreme heat, and concerns are also raised regarding air quality. Therefore, citizens may believe that initiatives like improving air quality, implementation of cooling technologies, and urban greenery should be increased. On the other hand, environmental control factors also help in the development of public spaces that are usable, accessible and safe, encouraging citizens to engage in outdoor activities. Citizens also believe that it is possible to develop more resilient and healthier cities by addressing environmental issues [24].

The study also revealed that IoT services have a positive effect on urban liveability, as discussed in the research by Sharma, and Jangirala[48]. The Saudi citizens are of the view that IoT services enable responsive urban management. The administration can have real-time monitoring of air quality, waste collection, energy usage, and traffic flow. Thus, IoT helps in the development of convenient as well as efficient city services that later improve the daily experiences of the residents. The citizens mentioned that the smart traffic system of the city helps in reducing stress, enhancing mobility, and reducing commuting time and congestion. Moreover, efficient resource management is provided by utilities that are IoT-enabled. The respondents are also of the view that urban liveability can be strengthened by the integration of IoT, as it will ensure a cleaner and safer city environment.

According to statistical results, infrastructure and urban development also have significant effects on urban liveability. The respondents of the city opined that infrastructure and urban development play a vital role in shaping the functional and physical aspects of the city. If the infrastructure of the city is well-planned to include public facilities, utilities, and transportation systems, the accessibility of the residents enhances. The travel time of the citizens can be reduced, leading to improved mobility through the integration of IoT in road networks. A more engaging living environment can be created by modern urban development projects, including mixed-use spaces, walkways, and parks, creating a healthier and happier environment for the public. The findings of Jodder*, et al.*[21] are in line with the results of present research.

Present research also supported the mediating role of urban liveability, similar to studies discussed by Nicolas*, et al.*[47].The plausible reason for these findings can be that the respondents may believe that the quality of infrastructure and development in KSA improves the usage of energy in an efficient way, leading to the enhancement of liveability. Moreover, urban and infrastructure development play a very important role in meeting the citizens' needs in KSA with minimal environmental impact. Also, smart technology like IoT systems has the ability to monitor systems efficiently, leading to operational efficiency in cities. Integration of all these three factors leads towards urban liveability, which later mediates towards energy efficiency and smart urban sustainability.

LIMITATIONS AND FUTURE DIRECTIONS

Along with several empirical investigations, the present study has certain limitations that provide avenues for future research. Firstly, this research proposed a conceptual framework incorporating one mediating variable, three independent variables, and two dependent variables. Future studies may consider expanding the model by introducing moderating variables such as urban efficiency and focusing on a single dependent variable for a more streamlined analysis. Secondly, the study employed a quantitative research methodology for data collection and analysis. It is recommended that future research adopt a mixed-methods approach to allow for deeper insights and contextual understanding.

Thirdly, data analysis was conducted using Smart PLS 4, a contemporary and widely accepted tool for structural equation modeling. Despite its strengths, future researchers are encouraged to explore alternative analytical software, such as AMOS, to compare results and validate findings. Lastly, data for this study were collected exclusively from residents of Riyadh. Future investigations should aim to include respondents from multiple cities across the Kingdom of Saudi Arabia to enhance the generalizability of the results.

THEORETICAL AND MANAGERIAL IMPLICATIONS

The present study examined the effects of IoT systems, environmental concerns, and infrastructure and urban development using a quantitative approach, with data collected from citizens of Riyadh. The research offers practical guidelines and applicable strategies for future urban development initiatives. Findings indicate that focusing on IoT systems, environmental considerations, and infrastructure development contributes to enhancing energy efficiency and achieving smart urban sustainability through improved urban liveability. Based on these insights, the study can serve as a foundation for designing integrated strategies aimed at promoting both sustainability and urban growth. From a theoretical standpoint, this research introduces a methodological framework that contributes to understanding the dynamics of urban liveability and its role in advancing energy-efficient and sustainable smart cities.

The results of the study also carry significant managerial implications. Urban planners can utilize these findings to formulate effective strategies that promote energy-efficient urban development. Furthermore, the proposed framework underscores the proactive role of IoT systems in enhancing urban liveability. Urban planning authorities in Saudi Arabia are encouraged to prioritize environmental concerns alongside infrastructure development to effectively support urban liveability. Strengthening this dimension is critical to the achievement of sustainable urban development. Additionally, the findings provide valuable policy direction for decision-makers, emphasizing the need for policies that strategically advance urban liveability objectives.

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