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Enhancing Walkability in Smart Cities: A Comprehensive Literature Review and Strategic Framework

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ABSTRACT

This paper explores the intersection of urban planning and smart city technologies in enhancing walkability, a crucial aspect of creating sustainable and livable urbanenvironments. Through an extensive literature review, the study identifies key factors contributing to walkability, such as safety, accessibility, and comfort, and examines thebenefits of walkable cities, including improved public health, economic vitality, and social equity. The concept of the "15-minute city" is introduced as a model for promoting walkability by ensuring access to essential services within a short distance. Additionally, the paper discusses technological advancements and case studies of successful walkability initiatives in smart cities worldwide, highlighting the role of smart walkways, street lighting, public spaces, crosswalks, bike-sharing systems, and digital placemaking in enhancing pedestrian experiences. The comparative analysis of different approaches and strategies provides insights into their key features, benefits, and challenges, offering a comprehensive overview of the current landscape in this field. The study concludes with recommendations for future research and practice to address existing gaps and challenges and further promote walkability in smart cities.

Keywords: Walkability, Urban Planning, Smart Cities, Smart Technology, Pedestrian-FriendlyDesign, City Planning.

INTRODUCTION

Urban planning is a multifaceted discipline that aims to create sustainable, functional, and livable urban environments. One critical aspect of urban planning that has gained increasing attention in recent years is the concept of walkability. Walkability refers to the ease of walking within a neighborhood or city, considering factors such as safety, accessibility, and comfort (Speck, 2013). The importance of walkability in urban planning cannot be ignored, as it has significant implications for economic development. By designing more walkable neighborhoods and cities, urban planners can create vibrant, thriving communities that attract businesses and increase property values (Shrestha, 2020).

Urban planning has come a long way in recognizing the importance of walkability in shaping cities that prioritize the well-being of their residents. Previously, cities were designed around the automobile, resulting in sprawling suburbs and car-centric infrastructure that limited pedestrian activity (Speck, 2013). However, as concerns about sustainability, public health, and social equity have become more prominent, planners have shifted their focus toward creating walkable neighborhoods that promote active transportation and community engagement. Studies have shown that walkable cities have been associated with numerous benefits, such as increased physical activity levels, reduced traffic congestion, improved air quality, and stronger social connections among residents (Shrestha, 2020). Implementing walkability in urban design can also lead to economic benefits, with studies showing that walkable neighborhoods tend to have higher property values and attract more businesses (Speck, 2013).

The practice of "smart cities" has become a crucial paradigm for urban development in recent times, with the

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objective of improving the standard of living for inhabitants by incorporating cutting-edge technologies and data-driven solutions. Intelligent urban areas utilize digital infrastructure, the Internet of Things (IoT), and artificial intelligence to enhance several urban functions, such as trash management, public safety, energy management, and transportation. But even with all technological progress, the success of these smart city efforts depends on the basic layout and operation of metropolitan areas. (Ratti & Claudel, 2016).

The extent to which the built environment facilitates and promotes walking, or walkability, is a crucial factor in the sustainability and livability of metropolitan regions. It is a crucial element that affects social interaction, public health, environmental sustainability, and economic viability. There are several advantages to living in walkable cities, such as decreased air pollution, fewer greenhouse gas emissions, increased physical exercise, and better mental health results. Walkable communities also encourage local business and community contact, which contribute to social cohesion and economic development. (Gehl, 2010; Litman, 2013).

Improving walkability inside smart cities requires incorporating cutting-edge technologies in addition to conventional urban planning techniques. For example, sensor-based lighting can increase safety, real-time data analytics can optimize pedestrian flows, and mobile applications can tell users of the best walks. Smart cities may develop more pedestrian-friendly settings that meet therequirements and desires of their citizens by using these technological solutions. With the goal of managing a city's assets and increasing service efficiency, smart cities entail integrating information and communication technology (ICT) with the municipal infrastructure. A key component of urban planning that affects social justice, environmental sustainability, and public health is walkability. (Ratti & Claudel, 2016).

This study aims to create a strategy framework for improving walkability in smart cities and undertake an extensive literature review. The advantages of walkability, the elements of a walkable environment, and how smart city efforts might strengthen these elements will all be covered in this study. This article highlights the obstacles encountered in promoting walkability and suggests effective practices through case studies of towns that have successfully incorporated walkabilityinto their smart city agendas. The ultimate objective is to offer insights into how cities might use technology and urban planning to develop livable, walkable, and sustainable urban environments.

Ojectives and scope of the paper

This paper aims to create a strategy framework for improving walkability in smart cities and undertake an extensive literature assessment. The following are the goals of this paper:

- Identify factors relevant to improving walkability in urban areas.
- Examine the advantages of being able to stroll around in cities.
- Determine the elements that go into creating a walkable environment.
- Analyze how integrating technology and urban design into smart city efforts might improve walkability.
- Examine case studies of cities to determine best practices and obstacles for incorporatingwalkability into smart city agendas (Gehl, 2010; Litman, 2013; Ratti & Claudel, 2016).
- To do these, the following two questions will be addressed:
- How can smart city design promote active transportation through walkability?
- What technologies enhance walkability in modern smart cities?

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI | Special Issue |Volume XI Issue XIV October 2024

LITERATURE REVIEW

In the last decade, walkability has attracted several researchers, where introducing walkability criteria and evaluation methods was their major focus point. Clifton and Livi summarized some attributes that resulted in walkable neighborhoods, which are: destination, convenience, continuity, system coherence, safety, attractiveness, and aesthetics (Clifton & Livi, 2005). Siddique, Kabir and Taher, (2017) mentioned that other studies give some key elements for designing walkable neighborhoods: direction routes, connectivity, calm traffic, safe street crossing, mixed-use density, visual interest, amenities, transit link and accessibility.

A new concept comes across the urban planning known as 15 -minute city. A 15-minute city is an urban planning concept where residents can meet most of their daily needs within a short 15 -minute walk or bike ride from their homes. This model aims to reduce dependence on cars, lower carbon emissions, and improve overall quality of life by ensuring access to essentials like groceries,healthcare, schools, parks, and workplaces within a compact urban area. By promoting mixed-use development and enhancing local infrastructure, 15-minute cities encourage sustainable living and foster community engagement. According to Moreno et al., (2021), this approach can significantly contribute to urban sustainability and resilience by reducing traffic congestion and pollution, thus supporting healthier, more livable urban environments.

This concept became more popular and is directly related to city walkability. Several studies focused on understanding the main factor influencing 15-minute cities and proposed a framework to measure it and improve walkability. Aparicio et al., (2024), presented a study that addresses the concept of 15-minute cities by defining and measuring walkability at a neighborhood and city level globally. The results indicate an inverse relationship between the number of communities meeting the 15-minute target, population growth, and city area. The study emphasizes the significance of addressing walkability issues in larger cities to ensure access to essential services. It was concluded by providing a framework for understanding walkability needs at a neighborhood level and suggesting optimized weight assignments for community generation.

Other studies have started testing the possibility of implementing this concept in existing cities. (Akrami et al., 2024) in their study investigates the feasibility of the 15-minute city concept in Oslo, Norway, by evaluating the accessibility of vital services, facilities, and green areas within a 15- minute walk. It also explains how this concept might be widely applied in urban planning. The study takes a mixed-methods approach, using Geographical Information Systems (GIS) analysis to assess accessibility, reviewing related plans, conducting interviews with planners, and conducting a case study in the Hovinbyen area. The study concluded that, while Oslo has characteristics of a 15- minute city, there is a significant gap between its inner and outer areas, indicating the need for a more comprehensive and inclusive urban design approach.

In their research, Sonta & Jiang (2023) investigate how urban design affects the sense of community within neighborhoods, focusing on how walkable areas contribute to social cohesion. The study measured neighborhood-level social cohesion using four indicators: close-knit relationships, trust in neighbors, willingness to help, and the number of known neighbors. The findings revealed that neighborhoods with various land uses tend to have stronger community bonds. On the other hand, areas with high physical and social density and extensive transit networksoften see weaker social connections, particularly in very crowded cities.

Walkability has several benefits for the community, economy, and environment. Some of these benefits are health, safety, pollution reduction, economic benefits, and social interaction. (Shamsuddin et al., 2012). The University of Delaware added more walkability benefits: transportation equity, promoting active life, reducing traffic, and encouraging using public transportation. (Michalowski, 2012). The above benefits are discussed more below:

Health: Recent research shows that cities that have car-dependent urban planning and less active mobilities are recording a dramatic increase in health problems and obesity (Bahrainy & Khosravi, 2013). Urban green

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spaces play a pivotal role in enhancing public health and well- being, particularly in the context of urban planning and walkability. Research has shown that the presence of green spaces significantly influences the mental well-being of children aged 8-13, emphasizing the importance of incorporating nature into urban environments (Ashok Biradar, 2024). Moreover, individuals with disabilities are often overlooked in urban planning processes. However, they stand to benefit considerably from access to green spaces, contributing to their overall quality of life and societal inclusion (Selanon & Chuangchai, 2023).

Safety: Street-level activity occurs when community members meet while walking, which could affect street safety.

- Using active transportation (walking and biking) could reduce pollution due to the intensive car use on urban streets.
- Economic Benefits: Walkability influences the economy from many sides, such as lower transportation costs, attracting people, and increasing commercial performance on that street.
- Social interaction: Where walking provides an opportunity for people to meet and interact.
- Reduce traffic: Where it would reduce the number of individual cars in the streets.
- Transportation equity: Since some people in the community cannot own their mobility, walkability gives them a sense of equity.
- Promote active movement life: Properly designed cities encourage communities to walk or cycle, which could change people's attitudes and promote active mobility.
- Public transportation benefits: Traffic and pollution will decrease using such a kind of transportation.
- A comfortable environment plays a major role in making walking an enjoyable journey (Sarkar, 2003). Recent studies discussed the strategies that make environments walkable and improve walkability. Some discussions on walkability propose that enhancing walkability plays a major role in solving most urban form problems (Forsyth, 2015). Cervero & Kockelman, (1997) defined the variables that mostly influence walkability and called them 3Ds: design, diversity, and density. Briefly, the 3Ds factors are (Cervero & Kockelman, 1997):
- Design: Several research studies have mentioned elements and quantities defining the design part. Özbil, Yeşiltepe, & Argin (2015) studied road design by testing asthmatic conFigureuration, safety, signage, walkway design, traffic lights, pedestrian crossing, connectivity, accessibility, and ground floor uses. (Sulaiman, 2020) mentioned in his review that the design could include walkway material, canyon height, width, parking arrangements, orientation, streetscape, and vegetation (shading). Walkways can make people's movement easier, consisting of any walkwaysexplicitly designed for pedestrians and their activities (Sarkar, 2003), where healthy streets should provide choices for active modes of transportation such as: walking and biking (Sarkar, 2003). Each design element works in forming a pedestrian perception of the environment. The decision to repeat walking in this space is formed depending on the memories that pedestrians gain.
- Diversity: It refers to land mix-used, which clarifies various available functions in the area. It is measured as a density defined as the variety of functions within a constrain (Sulaiman, 2020).
- Density: (Sulaiman, 2020) found through his research that most studies consider this factor as thepopulation and density of an area.

In general, most researchers confirm that design factors affect walkability the most (Özbil et al., 2015).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI | Special Issue |Volume XI Issue XIV October 2024

Technological advancements and their impact on walkability in smart cities

1- According to Pohl and Buchanan (2023), technological developments such as the Internet of Things, big data analytics, and sensor networks can improve security for pedestrians, navigation, and general transportation in cities. The incorporation of these smart technologies contributes to more efficient and pedestrian-friendly urban environments (Pohl & Buchanan, 2023).

2- Woo, Nam, and Chathoth (2018) highlighted Dubai's smart city initiatives, namely how smart tourism and urban technologies promote walkability. They discovered that implementing smart systems improves user experiences and urban navigation, hence contributing greatly to the city's general walkability (Woo, Nam, & Chathoth, 2018).

3- Dehgani and Navimipour (2019) investigated how advances in energy-efficient technology affect urban mobility and walkability. They emphasized the importance of smart grids and sustainable infrastructure in supporting walkable cities, emphasizing that such technology advancements benefit both environmental sustainability and improved human environments (Dehgani & Navimipour, 2019).

4- Balogun, Ogunlela, and Salihu (2020) examined several smart parking technologies and their effects on urban walkability. They discovered that by decreasing the requirement for substantial car parking spots, these technologies help to create more pedestrian-friendly metropolitan environments, increasing walkability (Balogun, Ogunlela, & Salihu, 2020).

5- Giffinger and Gudrun (2020) suggested a framework for incorporating technological improvements into smart cities to improve urban mobility and walkability. They emphasized the application of artificial intelligence and machine learning to enhance pedestrian paths and urban design, implying that these technologies can considerably increase walkability (Giffinger & Gudrun, 2020).

6- Neirotti et al. (2021) presented case studies from several smart cities throughout the world, demonstrating how smart technologies have been used to encourage walking. They highlighted the actual uses and problems of applying these technologies, offering ideas into how to effectively promote walkability in urban settings (Neirotti, De Marco, Cagliano, Mangano, & Scorrano, 2021).

7- Wang (2024) research delves into the concept of creating smart neighborhoods through digital placemaking, specifically focusing on older urban areas in Hong Kong. It highlights the pivotal role of residents in shaping these smart neighborhoods through their interactions and the sharing of information about local events. Instead of relying on traditional smart technologies like lampposts and CCTV cameras, the study found that the most significant digital-physical attributes contributing to smart neighborhoods were the residents and their digital possessions, such as smartphones and wearable devices. The research highlighted that residents armed with smart devices actively participated in making their neighborhoods smart by determining the data they needed and how they wanted to collect and share it. This active involvement of residents in digital placemaking was identified as a key mechanism for the emergence of everyday urban smartness. development. (W. Wang, 2024).

Case studies of successful walkability initiatives in smart cities

Many cities implement smart solutions to enhance walkability and create more pedestrian-friendly environments. Here are a few examples:

1. Singapore: Smart Walkways and Connected Parks: Singapore has implemented a system of intelligent walkways with sensors to monitor and regulate pedestrian traffic, ensuring safety and convenience. The city also connects its parks through the Park Connector Network (PCN), providing continuous green pathways for walking and cycling (Tanuwidjaja, 2011).

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI | Special Issue |Volume XI Issue XIV October 2024

2. Barcelona, Spain: Barcelona is a leader in smart city initiatives. The city has implemented smart street lighting, which adjusts brightness based on pedestrian presence, enhancing safety and walkability. Additionally, the city's extensive network of sensors and IoT devices collects data to optimize urban mobility and public spaces, encouraging more walking and reducing congestion (Visvizi et al., 2021)

3. Seoul, South Korea: Seoul has transformed itself into a smart city by integrating technology into its urban infrastructure. The restoration of the Cheonggyecheon Stream is a prime example. This project transformed an old highway into a 10.9 km public park with pedestrian pathways, promoting walkability and environmental sustainability. Additionally, Seoul employs smart crosswalks equipped with LED lights and sensors to alert drivers to pedestrians, improving safety (Rethinking the Future, n.d., 2023).

4. Copenhagen, Denmark: Known for its commitment to sustainability, Copenhagen has implemented various smart city solutions to promote walkability and cycling. The city uses a smart bike-sharing system that integrates with public transport, encouraging a seamless transition between biking and walking. Sensors installed throughout the city monitor air quality and traffic patterns, providing real-time data to optimize pedestrian routes and reduce pollution exposure (McKinsey, n.d., 2018).

FINDINGS

The above literature reveals a multifaceted relationship between urban planning, technological advancements, and community well-being. Walkability is crucial for creating sustainable, functional, and livable urban environments, encompassing safety, accessibility, and comfort, significantly influencing economic development, public health, and social equity.

Historically, cities were designed around automobiles, leading to sprawling suburbs and car-centric infrastructures. However, recent shifts in urban planning prioritize pedestrian-friendly environments due to growing concerns about sustainability, public health, and social equity. Walkable cities offer numerous benefits, including increased physical activity, reduced traffic congestion, improved air quality, and enhanced social connections. Additionally, economic benefits include higher property values and the attraction of businesses. The concept of smart cities integrates cutting-edge technologies like IoT, AI, and data analytics to enhance urban functions, including walkability. Technological advancements can improve pedestrian safety, optimize pedestrian flows, and provide real-time information to enhance the walking experience.

Key elements contributing to walkable neighborhoods include connectivity, mixed-use density, safe street crossings, visual interest, and accessibility, essential for encouraging walking and active transportation. The 15-minute city concept emphasizes that residents should be able to meet most of their daily needs within a 15-minute walk or bike ride, reducing car dependence, lowering carbon emissions, and enhancing overall quality of life by promoting mixed-use development and local infrastructure improvements. Technological advancements such as smart lighting, real-time data analytics, and smart parking systems enhance walkability by improving pedestrian safety, optimizing urban navigation, and creating more pedestrian-friendly environments. Various cities worldwide have successfully implemented smart solutions to enhance walkability. For example, Singapore's smart walkways and connected parks improve pedestrian safety and convenience, while Barcelona's smart street lighting and sensor networks optimize urban mobility and encourage walking. These insights highlight the critical role of walkability in urban planning and the transformative potential of integrating smart technologies to create sustainable, livable, and vibrant cities, underscoring the need for a holistic approach combining traditional urban planning principles with modern technological innovations.

Despite the substantial research on walkability and smart cities, several gaps and challenges remain. One significant gap is the lack of comprehensive frameworks that integrate walkability into smart city initiatives in a way that considers the diverse needs of all urban residents, including the elderly, children, and people with disabilities. While numerous studies highlight the benefits of walkability, there is limited research on the

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specific technological solutions that can be effectively implemented in different urban contexts, particularly in cities with varying sizes and population densities. Additionally, most existing studies focus on developed countries, leaving a gap in understanding how walkability and smart city technologies can be adapted to developing nations' unique challenges.

Another challenge is measuring and evaluating walkability. Although various metrics and criteria have been proposed, no universally accepted standard for assessing walkability makes it difficult to compare results across different studies and cities. The dynamic and multifaceted nature of walkability, which involves physical, social, and environmental factors, adds to the complexity of developing robust measurement tools. Furthermore, the rapid pace of technological advancement challenges urban planners and policymakers to stay updated with the latest innovations and effectively incorporate them into city planning.

The integration of smart technologies into urban environments also presents challenges related to data privacy and security. As cities deploy more sensors and data collection devices to enhance walkability, concerns about protecting personal information and the ethical use of data become increasingly prominent. Additionally, implementing smart city technologies often requires significant financial investments and infrastructure upgrades, which can be a barrier for cities with limited resources.

Lastly, there is a need for more interdisciplinary research that bridges the gap between urban planning, technology, and social sciences. Such collaboration is essential to address the complex interactions between the built environment, technological systems, and human behavior. By identifying and addressing these gaps and challenges, future research can contribute to more effective and inclusive strategies for enhancing walkability in smart cities.

Comparative analysis of different approaches and strategies

The concept of walkability is increasingly recognized as a crucial component of urban planning, especially within the framework of smart cities. Walkability refers to the ease and safety residents can walk through urban areas, significantly impacting public health, environmental sustainability, and economic vitality. As cities worldwide embrace smart city technologies, various approaches andstrategies are being implemented to enhance walkability. These include integrating smart walkways,adaptive lighting, restored public spaces, smart crosswalks, bike-sharing systems, and more. The following comparative analysis (Table 1) examines different approaches and strategies from scientific research focusing on improving walkability in smart cities. This analysis highlights key features, benefits, and challenges, providing a comprehensive overview of the current landscape in this field.

Table 1: Comparative Analysis of Walkability Strategies in Smart Cities

Approach / Strategy	Reference	Key Features	Benefits	Challenges
Smart Walkways and Sensors	Tanuwidjaja, 2011	Intelligent walkways with sensors to monitor traffic	Enhanced pedestrian safety and convenience	High implementation and maintenance costs
		Real-time data collection	Optimized pedestrian flows	Ensuring data privacy and security
Smart Street Lighting	Visvizi et al., 2021	Adaptive lighting based on pedestrian presence	Improved safety and walkability	Integration with existing infrastructure
		Energy-efficient and responsive systems	Reduced energy consumption	High initial setup costs

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI | Special Issue |Volume XI Issue XIV October 2024

Restored Public Spaces	Rethinking The Future, 2023)	Transformation of urban areas into pedestrian zones	Promotes environmental sustainability and walkability	High initial investment
		Incorporation of green spaces	Increased social interaction	Maintenance and operation costs
Smart Crosswalks	Rethinking The Future, 2023)	Crosswalks with LED lights and sensors	Increased pedestrian safety	High cost of technology implementation
		Alert drivers to the pedestrian presence	Improved traffic management	Continuous technological updates
Smart Bike-Sharing Systems	McKinsey, 2018	Integration with public transport	Encourages active transportation	Balancing technological upgrades with urban fabric
		Real-time tracking of bike availability	Reduced pollution exposure	Ensuring equitable access across different city areas
15-Minute City Concept	Moreno et al., 2021	Accessibility to essential services within 15 minutes	Reduced car dependence and lower carbon emissions	Bridging gaps between inner and outer city areas
		Mixed-use development	Improved quality of life	Adapting the model to different urban densities
Digital Placemaking	(S. Wang, 2024)	Residents use smart devices for data collection	Enhanced community engagement	Ensuring accurate and inclusive data representation
		Customizable urban solutions based on residentinput	Resident-driven urban improvements	Managing data privacy and security
Smart Parking Technologies	Channamallu et al., 2023	Efficient management of parking spaces	Reduced need for large parking areas, increasing walkability	Implementation costs and technological maintenance
		Real-time information on parking availability	Improved traffic flow and reduced congestion	Integration with xisting systems
Smart Street Furniture	Neirotti et al., 2014	Interactive benches with charging stations	Enhances pedestrian convenience and connectivity	High installation and maintenance costs
		Wi-Fi-enabled trash bins with sensors	Reduces waste management costs	Vandalism and misuse
		Smart bus stops with real-time information displays	Improves public transport usage	Integrating with existing public transport infrastructure

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI | Special Issue |Volume XI Issue XIV October 2024

CONCLUSION

Finally, this research emphasizes the importance of walkability in urban design, demonstrating the transformative potential of incorporating smart city technology to create sustainable, livable, and lively urban settings. Walkability, or the ease with which individuals can explore their city on foot, provides various benefits. It improves public health by increasing physical exercise, which lowers the incidence of chronic diseases like obesity, diabetes, and heart disease. Furthermore, walkable areas improve mental health by encouraging social contact and offering access to green spaces. Economically, walkable towns get more foot traffic, which benefits local businesses and improves property prices. Such landscapes attract both tourists and inhabitants, promoting a thriving urban economy. Socially, walkability ensures that all city residents, even those who do not own a car, mayquickly access important services, employment possibilities, and recreational places, fostering inclusivity and equitable chances across socioeconomic categories. The study investigates several tactics and ways to improve walkability in smart cities. These include the creation of smart sidewalks with sensors to monitor pedestrian traffic, adaptive lighting to improve safety, and uniquesurfaces that generate energy or offer users with real-time information. Intelligent street lighting canmodify brightness in response to pedestrian presence, improving both safety and energy economy. Digital placemaking uses digital tools to involve community members in the design and development of public spaces, ensuring that they fit the requirements of local citizens. Furthermore, smart parking technology can reduce the demand for additional parking spaces, freeing up more space for pedestrians and lowering rush hour traffic.

However, the study observes several critical gaps and problems that must be solved before the full promise of walkable smart cities can be realized. One important issue is a lack of comprehensive frameworks that incorporate diverse aspects of walkability and smart city technology while offering clear recommendations for urban planners. Effective measuring methods are also required to assess and monitor walkability, ensuring that policies are data-driven, and results are quantifiable. Furthermore, there is a need for multidisciplinary research that combines insights from urbanplanning, technology, sociology, and public health to build comprehensive and successful interventions. This study, as a complete literature review and strategy framework, presents the existing knowledge and techniques for improving walkability in smart cities. It combines multiple methodologies and identifies the most promising strategies, while also highlighting gaps and issues that must be addressed. Addressing these issues necessitates collaboration among urban planners, technologists, and social scientists. By collaborating, these professions may create inclusive and successful methods for improving walkability in smart cities. Using innovative technologies and urban planning ideas, cities may transform into more walkable, habitable, and sustainable spaces. These cities will prioritize pedestrians' needs and experiences, resulting in healthier, livelier, and egalitarian urban environments.

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