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Review

Examining the Role of Innovative Streets in Enhancing Urban Mobility and Livability for Sustainable Urban Transition: A Review

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Abstract: As an essential component of urban public spaces, urban streets play a crucial role in shaping cities and promoting urban sustainability. This article focuses on innovative streets as a catalyst for sustainable urban transition. It reviews the theoretical discussions, and empirical evidence on innovative planning approaches for urban streets. For that purpose, measures related to innovative streets are divided into two broad categories: urban mobility and urban livability. The results indicate that integrating smart street facilities with the Internet of Things (IoT), adopting a combination of grid and radial street networks, and fostering a safe street environment are vital in promoting urban mobility. Conversely, a walkable, rideable, and human-oriented street environment enhances social interaction and urban livability. The street's dual function as a commuting and social space highlights the interplay between rising mobility and intensive street usage, leading to competition for street space. To mitigate these conflicts and advance sustainable urban transitions, enhancing street safety, reducing disparities in planning and user behavior, and accommodating the needs of all street users is crucial. Overall, the evidence supports the contribution of streets to sustainable urban transition.

Keywords: innovative streets; sustainable urban transition; urban mobility; urban livability; street review

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1. Introduction

1.1. Background

Cities and urban neighborhoods are at the frontline of sustainability [1,2]. They are most vulnerable to ecological, socio-economic, and political crises; on the other hand, they are innovative hubs for sustainability transitions, providing multiple actors with opportunities to jointly experiment and test urban practices to create and establish new sustainable systems and infrastructures [3]. In this regard, transitions towards sustainability entail socio-spatial processes to overcome lock-in effects and the path dependencies of previous developments through innovative ideas and approaches [4]. Accordingly, sustainable urban transitions are purposeful, systemic, long-term, and vision-led changes towards sustainability. They can be understood as goal-oriented processes initiated to achieve sustainable targets in a complex set of urban practices, technologies, infrastructures, markets, and institutions. This requires long-term oriented governance approaches and flexible, adaptive, and reflexive policy designs that help re-shaping, re-defining, and establish urban sustainability [2,5,6].

Sustainable urban transition thus involves reorganizing urban infrastructure, transportation, lifestyles, and neighborhood interactions to yield the co-benefits of urban efficiency and urban dwellers' well-being. Among these, sustainable urban infrastructure plays a critical role since the upgrade of public facilities and urban transportation has the potential to mitigate the adverse effects of climate change and urban sprawl.

Urban streets, as the backbone of urban infrastructure, serve a diverse array of functions, including transportation, recreation, socialization, and reproduction. Under the advocacy of Appleyard and Jacobs [7,8], streets progressively became a symbol of social places, taking on daily functions such as inhabitants' communication and social harmony. Despite the proliferation of street theories and approaches aimed at promoting urban sustainability through enhanced mobility and livability, a structured theoretical framework for using innovative street approaches to achieve sustainable urban transitions is yet to be established. Previous studies have partially examined the relationship between streets and active transportation patterns and the role of urban streets in increasing social resilience [9–11]. There is a lack of research on the relationships between street infrastructure, street network patterns, and traffic safety.

This review seeks to categorize innovative street design and measurement approaches while discussing the synergy of street mobility and livability to facilitate the sustainable urban transition. We aim to contribute to the field by filling the following gaps: (1) What are the theoretical perspectives and practical guidance on innovative street concepts that have been proposed? (2) What synergies and potential conflicts regarding sustainable urban mobility and urban livability on the street? (3) What considerations must be taken when planning and implementing innovative streets? The findings of this review have the potential to inform urban planners and decision-makers in creating sustainable and livable urban environments through innovative street design and management practices.

The review is structured as follows: The definition of innovative streets is elaborated in the remaining Section 1. Section 2 explains the research methodology and materials. Section 3 examines the current innovative street theory regarding urban mobility and livability. Section 4 critically discusses synergies, potential conflicts, recommendations, and principles for designing innovative streets. Section 5 provides the conclusion and further directions.

1.2. Definitions of Innovative Streets

As the arteries of the city, urban streets not only facilitate transport and commuting, they are also places for recreation and connectivity on different scales, with a commitment to enhancing urban mobility and livability [12]. Figure 1 illustrates how innovative streets emerge at the interface between sustainable urban mobility and urban livability and what characteristics and attributes are associated with it.

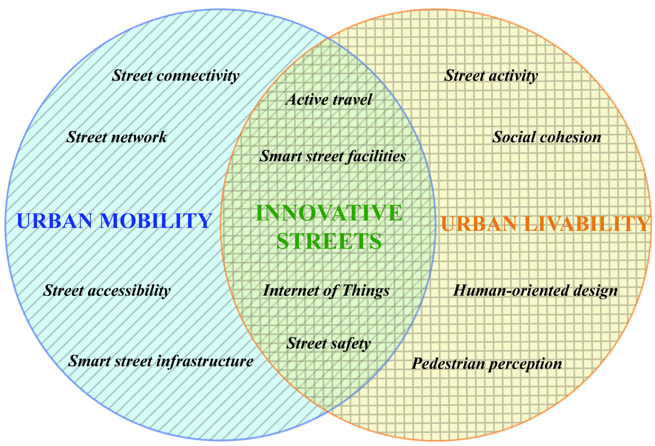

Figure 1. Innovative streets as an integrative urban practice.

2. Material and Methods

2.1. Research Scope and Search Strategy

The review concentrates on published articles in the Web of Science and Scopus databases. Only articles between January 2000 and May 2021 that were published in English journals were selected. As the conceptualization of innovative streets is not clearly defined, the scope is narrowed down to urban streets, which considerably impact social interaction and community cohesion. This allows data extraction in comparable settings [13]. Terms and keywords related to the concept of innovative streets also include synonyms such as "neighborhood street", "innovative street", "walkable street", "livable street", "sustainable street", "calm street", or "creative street" were searched as the first step. The search was not limited by street; therefore, synonyms such as "avenue", "boulevard", and "road" were included. However, synonyms with a tenuous connection to the street were excluded from the search due to the topic's divergence, such as "street crime" or "street sewage treatment". The second step was to relate the concept of innovative streets with urban planning and sustainability. Here, the different concepts combined with "sustainable urban transition" or "sustainable urban planning" to identify the correlation between innovative streets and sustainable urban transition; 444 articles met the set conditions.

2.2. Procedure and Data Extraction

The procedure for data extraction consists of two progressive steps (Figure 2). A review of the abstracts of all the articles was studied to determine if they contributed to the research topic. Particular classifications were used to select the most eligible articles:

- High level: the keywords, related terms/concepts, and conclusion of the article are highly relevant to both streets and sustainable urban transition. For instance, longitudinal research of neighborhood commercial streets in Boston has identified the relationship between physical street design, resident behavior, and urban livability [14]. Such publications contribute to the advancement of innovative streets.
- Medium level: the terms and concepts overlap with this review; however, there is sufficient content, such as case studies. Articles that examine design features for transportation or environmental purposes but do not consider street design as a means of increasing urban sustainability are considered to be of moderate relevance and are omitted.
- Low level: topics have little relevance to this review. Some papers concentrate on urban poverty and sewage management, with the street having a minimal role in the research. These articles are excluded.

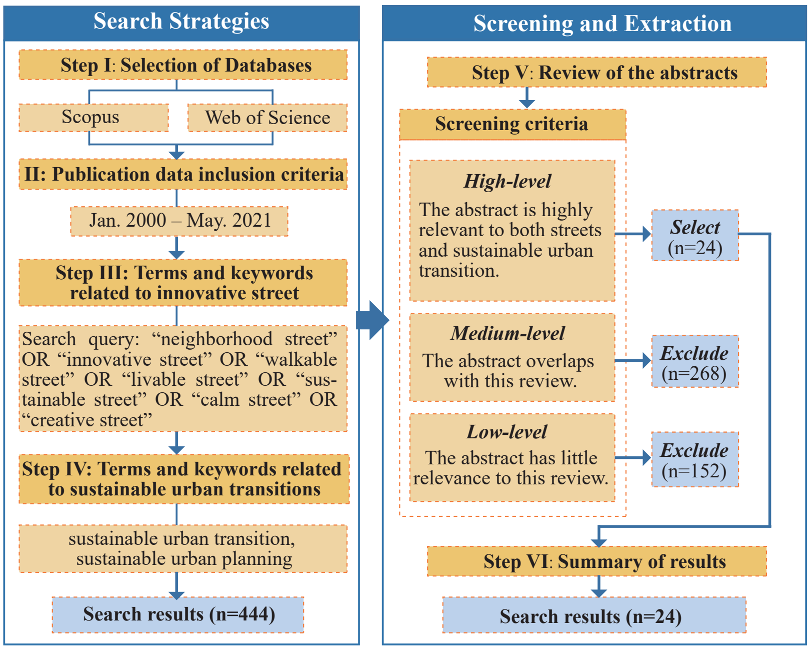

Figure 2. Flow chart of the applied process to select papers for this review.

Finally, 24 articles were selected for the analysis, dealing with innovative street approaches and sustainable urban transition.

3. Results

As shown in Figure 3, the high-frequency keywords were then identified and clustered using keyword co-occurrence analysis in Citespace. The specific keywords are then listed in Table 1, and six sub-themes were categorized into two clusters, i.e., urban mobility and livability, to explain the contribution to sustainable urban transition. Tables 2 and 3 compare these publications cross-sectionally by their research objectives, factors examined, and results.

The results of this study reveal a broad geographical representation among the selected papers, with a mix of global and regional perspectives. Four articles (16.7%) present a worldwide outlook, while eight articles (33.3%) focus on cities in North America, particularly the United States (seven articles). Europe is the subject of investigation in six articles (25%), while four (16.7%) explore cities in China. The remaining two articles (8.3%) address technical matters. Nonetheless, geographical similarities were discovered, with all studies selecting cities with a high level of development, such as cities in developed countries or major cities in developing countries such as Hong Kong. This may be due to the abundance of street pilot studies and readily available geographic information in these locations.

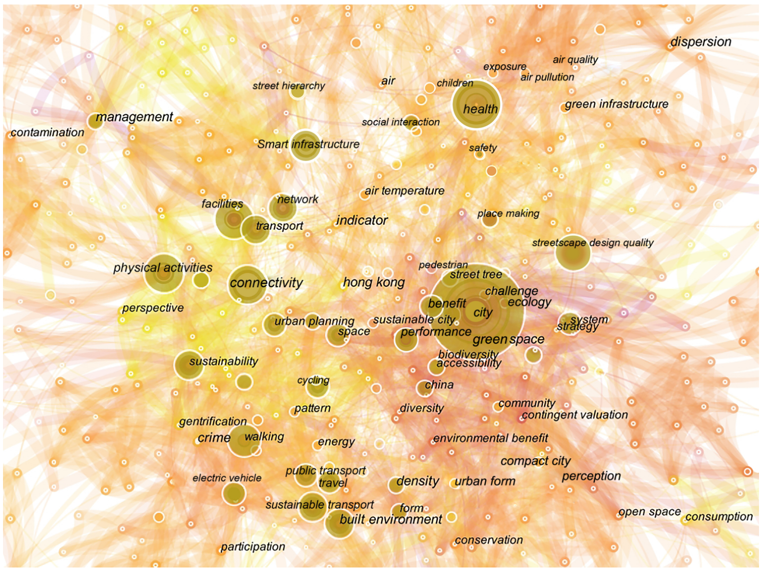

Figure 3. Results of a preformed keywords co-occurrence of the 444 articles reviewed on innovative streets related to sustainable urban transitions.

Table 1. Categorization of high-frequency keywords into six sub-themes.

Research Topic	Keyword Co-Occurrence Analysis	Sub-Themes
Urban mobility	Smart infrastructure, facilities, management	Smart street infrastructure
	Connectivity, accessibility, density, street hierarchy, street network	Hierarchical street network
	Safety, children, accessibility	Safe streets as a guarantee of access
Urban livability	Physical activities, social interaction, health, place making	Street activities to enhance social interaction
	Streetscape design quality, pedestrian, physical environment	Human-centered Street environment design
	Walking, cycling, sustainable transport, public transport, travel, electric vehicle	Active travel and its assessment criteria

3.1. Urban Mobility

The co-occurrence analysis of 24 articles indicates that the innovative streets related to urban mobility involve numerous aspects (Table 2). First, smart street infrastructure examines the current development of street infrastructure, creative practices, and on-street facilities. Second, hierarchical street networks elucidate the optimal network structure to maximize urban transportation efficiency. Third, safe streets synthesize macro-, micro-, and application-level commonalities in street safety design to ensure the accessibility of the street and the safety of the street users.

3.1.1. Smart Street Infrastructure

Sustainable urban transition aims to make optimal and sustainable use of urban resources. Well-equipped streets increase environmentally friendly travel and decrease the use of automobiles [15,16]. Our survey indicates that street infrastructure, including street parking, charging facilities, smart furniture, and smart lighting, will create opportunities for urban sustainability.

Street Parking

Marshall, Garrick, and Hansen [17] propose a combination of on-street parking with diverse land uses that provide convenience while stimulating retail businesses, which ensures accessibility to urban land and increases productive use. For better access to information about parking spaces, Gu et al. discovered that by applying wireless sensor networks to the street parking system (SPS) while proposing a state machine-based parking algorithm, the state of on-street parking can be managed efficiently [18,19]. The proposed SPS consists of a computer server, a base station, routers, end devices, and an LCD board. The high-precision parking algorithm and fast feedback in this wireless sensor network-based SPS promote the efficient use of street parking and redefine the land use of the parking area.

Street Charging Facilities

Plug-in electric vehicles (PEVs) are an effective alternative to gasoline-powered automobiles [20,21]. However, with the advent of new technology, travelers' dependence on charging stations has increased significantly. Grote, Preston, Cherrett, and Tuck [22] employed population and parking data to assist authorities in Southampton, United Kingdom, in identifying suitable places to install charging devices in residential areas. The study has shown that the installation of wireless charging via electromagnetic induction pads embedded under on-street parking spaces and on the undersides of vehicles, as well as the development of rapid charging stations in significant street parking areas, incentivizes citizens to adopt shared charging solutions and leads to the attainment of related environmental benefits.

Smart Furniture

Numerous studies have highlighted street furniture for its essential role as street infrastructure to enhance the comfort of pedestrian travel and outdoor activities [23]. In May 2016, New York City Commission announced the launch of a new pilot initiative involving the installation of multi-purpose benches to build a sustainable city [24]. These smart benches offer complimentary mobile charging, and interactive devices display geographic information about nearby amenities. They function as connection points for IoT to transmit data to terminals [19]. While walking on these streets, pedestrians grasp street amenities, urban functions, and transit routes.

Smart Lighting

Currently, there is power saving by providing street lighting with energy-efficient LED lights. Installing solar panels on street lights to collect solar energy and convert it to electricity can provide the city with additional environmental benefits. Additionally, through intelligent control systems for the IoT, smart lighting enables more precise dimming control and shorter run times than traditional street lighting [24]. Many street-smart lights provide a reasonable basis for installing sensors that connect to the IoT to deliver road information.

Table 2. Articles examining the correlation between innovative street and urban mobility.

I: Smart Street Infrastructure			
Reference	**Objectives**	**Factor(s) Examined**	**Results**
[24]	To explore the technologies and projects implemented in NYC for building a smart city.	• Water management • Link NYC • Smart lighting	• In 2014, New York City popularized free WiFi, ensuring unlimited phone calls, device charging, and access to city services and maps. • The use of energy-efficient LED street lights to provide better lighting and reduces energy waste. Through the installation of sensors, traffic, pollution, and crime data can be collected. • Street and pedestrian data are collected through sensors deployed on the street and uploaded to the cloud for processing and output for smart street planning strategies.
[17]	To grasp the full scope of on-street parking, involving demand model, land use, and environment.	• Parking demand • Pedestrian environment • Traffic speed	• Assessing on-street parking increases the value of urban land use, while ensuring enough land for productivity. • Low-speed zones will be built only when on-street parking is incorporated with other countermeasures into urban design.
[22]	Identify potential locations for the initial installation of residential on-street charging infrastructure for Plug-in Electric Vehicle in urban areas.	• Charging infrastructure • Plug-in Electric Vehicle	• The proximity to public transport access points, as residents with easy transit access may have reduced road vehicle requirements. • The provision of such infrastructure removes barriers to purchasing electric vehicles, thus contributing to the associated environmental benefits. • Encourage street infrastructure to achieve environmental benefits by determining the initial installation location of electric charging posts in residential areas.
[18]	Introducing a street parking system to help manage on-street parking in high-density cities.	• Wireless sensor networks • Street parking system	• A street parking system based on wireless sensor networks and a parking algorithm based on state machine are proposed to improve street parking efficiency. • The street parking system consists of a computer server, a base station, routers, end devices, and an LCD board. • The vehicle detection accurate rate of the SPS is nearly 99%; therefore, the proposed SPS is energy efficient.
[19]	Using sensors organized through the wireless networks to inspire the infrastructure construction of the smart cities.	• Wireless network • Smart city • Environment monitoring	• The primary monitoring network uses street lights as routing and cabs as dynamic nodes. Collected information will be sent to the designated terminals as messages. • A smart urban environment monitoring system based on the wireless network of ZigBee was designed to complete the real-time collection of urban environment information.

Table 2. *Cont.*

II: Hierarchical Street Network			
Reference	**Objectives**	**Factor(s) Examined**	**Results**
[9]	To explore how urban streets can support urban resilience.	• Street centrality and connectivity • Street network typology • Street width, edge, layout and orientation	• It requires a different level of centrality to take advantage of the economies and construct urban services and infrastructure. • The connectivity of streets is essential for urban resilience, reducing the dependence on the automobile and increasing accessibility of urban resources. • Narrow streets should be linked to wide streets by designing the street network with mixed hierarchies.
[25]	The aim is to examine the effects of physical environment variables on active travel and residential activities, including urban streets.	• Street patterns • Physical activities • Walking and cycling	• Residents from communities with higher density, greater connectivity, and more land use mix report higher rates of walking and cycling. • Connectivity is high when streets are laid out in a grid pattern, and there are few barriers (e.g., walls, freeways). • Route distance is comparable to straight-line distance with high connectivity. In addition to direct routes, grid patterns provide a choice to reach the same destination.
[26]	To clarify understanding of the different kinds of network representations and their hierarchical properties and to provide a way of capturing street network structure.	• Street hierarchy • Road network • Route structure	• A mathematical retrofit and clarification of relations between graph-based and route structure approaches are proposed. • Street network structure is interpreted in terms of hierarchical relations. • Road hierarchy is of definite concern to road network design and management. • Continuity, connectivity, and cardinality could create a formal hierarchy of streets.
[12]	To assess the configuration and sustainability of street networks in China's superblocks.	• Route structure • Street connectivity • Street continuity	• The suitable streets for connectivity and sustainability are a combination of fine orthogonal grids and multiple sets of radiations that avoid the disadvantages of monotony. Nonetheless, the resulting triangular plots reduce functional adaptability. • Bottom-up, resident-led streets and semi-public spaces are narrowing the gap between different urban blocks.
III: Safe Streets as a Guarantee of Access			
Reference	**Objectives**	**Factor(s) Examined**	**Results**
[13]	To summarize the literature on the relationship between the built environment and traffic safety in the urban area.	• Traffic safety • Street network design • On-street parking • Street width	• The traffic environments of the dense urban environment appear to be safer than the lower-volume environments of the suburbs. • Less forgiving design approaches such as narrow lanes, traffic-calming measures, and street trees near the roadway improve safety performance in a dense area. • Create "clear zones" between sidewalk and roadway; adding street furniture and trees in this area helps reduce traffic collisions.

Table 2. *Cont.*

III: Safe Streets as a Guarantee of Access			
Reference	**Objectives**	**Factor(s) Examined**	**Results**
[27]	To determine the effect of street built environment characteristics on pedestrian safety.	• Cycle lanes • Street geometric • Street network • Sidewalk width • Paving quality • Street lights • Path slope	• The fundamental factor in street safety is speed. • On-street parking, the number of lanes, and the separation of pedestrians from the roadway result in increased danger of accidents. • The physical separation of the street prevents cars from the sidewalk and improves the streetscape but decreases the view and visibility of pedestrians. • Street parking requires a buffer zone to ensure pedestrian visibility, which can be achieved by narrowing the lane width.
[28]	To assess the effect of street and street network characteristics on street safety.	• Street connectivity • Street network density • Street network patterns	• High-density street network results in low collision rates due to travel patterns. Neighborhoods with a higher density of intersections have a lower percentage of residents who travel by automobile. • Increased intersection density is associated with a reduction in severe crashes due to lower vehicle speeds. • Increased intersection density, on-street parking, and bike lanes along streets contribute to lower vehicle speeds and improve street safety.

3.1.2. Hierarchical Street Network

The characteristics of streets conducive to sustainable urban transition are generally summarized as follows: high connectivity that provides circulation efficiency, high complexity that reinforces centers and responds to the demand of daily life, and suitable depth that ensures a reasonable distance from any place in the street to the nearby facilities [29]. The hierarchical structure of the street network represents a multi-scale classification of daily activities and urban efficiency. It should be meticulously planned and strictly regulated to establish a framework that enables sustainable development while facilitating bottom-up renewal within an appropriate hierarchy [12].

Using a mathematical retrofit and clarification of relations between graph-based and route structure approaches, Marshall [26] emphasized the impact of the different continuity and termination of streets through junctions on the street hierarchy rather than "node-centric". He clarified that any properties of continuity, connectivity, or cardinality, suitably ranked or combined, can create a formal hierarchy of streets. Saelens, Sallis, and Frank [25] suggested that a network of streets with a grid pattern without barriers results in superior connectivity and better traffic efficiency, providing more route options for pedestrians, cyclists, and drivers. Sharifi [9] compared the performance of gridded and dendritic networks and found that well-connected streets exhibit characteristics of both typologies, featuring a hierarchical pattern of centrality distribution and cross-connections. A scale-hierarchical street design allows for greater adaptability to changing conditions and enhances the connectivity and complexity of urban streets in their interactions with other urban functions [9,26].

Findings have been derived to enhance the efficiency of urban mobility. Ge and Han [12] leveraged Marshall's street path analysis model to identify the attributes of the most sustainable streets, which were found to have fine orthogonal grids and abundant radiations. The study highlights that a "small block and dense network" approach can offer high connectivity and enhance the linkages between communities and cities, and is closely intertwined with the macro-scale street network that is pivotal to the sustainable development of urban transportation, commuting, and daily activities.

3.1.3. Safe Streets as a Guarantee of Access

The relationship between street network typologies and urban street safety has been analyzed in macroscopic studies. The findings support the notion that street networks with loop and lollipop forms are safer than gridded street networks [30–32]. Furthermore, the density of intersections plays a significant role in travel decisions, and driver behavior since high-density intersections lead to fewer and relatively minor car crashes [33]. This correlation is further demonstrated by the observation that neighborhoods with higher intersection densities also tend to have a lower percentage of residents who commute by car. High-density residential streets can disperse congestion on arterials, allowing cities to build arterials with fewer travel lanes while providing more space for walking and cycling [13,28].

The microscopic study discusses the coexistence of roadways, sidewalks, and on-street parking. The views are controversial. Ewing and Dumbaugh [13] advocated spatial separation between sidewalks and roadways by creating broad "clear zones" and adding street trees, concrete planters, and other fixtures to reduce vehicle-to-pedestrian collisions. Conversely, opposing views indicate that these physical separations led to hazards by reducing the visibility of pedestrians, especially for children and the elderly [27]. The issue of on-street parking is equally controversial in terms of street safety, with Congiu, Sotgiu, Castiglia, Azara, Piana, Saderi, and Dettori [27] pointing out that on-street parking increases the risk of crashes by two times, and the cause of car–bicycle collisions is unexpected "dooring." Nevertheless, on-street parking has been shown to improve traffic safety since it is used to buffer the pedestrian realm from potentially dangerous oncoming traffic and to clarify the spatial configuration of the public right-of-way. Another supportive argument shows that the low speed when parking reduces accidents' severity [28]. The contribution of the "clear zones" between sidewalks and roadways and on-street parking to street safety remains a topic of study. It requires examination across diverse urban environments, such as high-density and low-density areas.

3.2. Urban Livability

While urban streets have the potential to drive sustainable urban transition regarding urban efficiency, travel experience, street infrastructure, and user safety, they also serve as open urban public places that facilitate social interaction and everyday activities. Section 3.2 looks at how urban streets operate as social places.

3.2.1. Street Activities to Enhance Social Interaction

The great potential for social inclusion and interaction is at everyone's doorstep, and the streets are a great place for social integration [34]. This implies that inhabitants may engage in the street, directly and indirectly, increasing both stationary and continuous activity. These short-term, low-intensity possibilities for easy engagement represent the start of longer-term encounters and signify that the street serves as a public space. A significant body of literature underscores the street's role as a learning environment for children, providing exposure to various people and activities. Beyond its educational benefits, the street also serves as a site for adult learning since street users can be motivated to engage in new activities by watching other interactions [35–37].

Biddulph [37] examined urban neighborhood streets in seven home zones in the UK to investigate the role of livable streets in encouraging users' activities. It was found that children were the primary beneficiaries of livable streets, engaging in play activities with relative freedom across the entire area. Adults were also observed spending extended periods on the streets responding to children's presence. Sauter and Huettenmoser [34] explored the relations between street design, traffic, and social interaction. The study discovered that streets with slow-moving traffic, limited parking space, and positive environmental qualities offer a significant opportunity for personal encounters and urban relations. This aligns with the conclusions drawn by Biddulph [37], who highlighted the significance of the street structure, such as layout, and speed restrictions, in promoting social interaction and inclusion. In this regard, street structure emerged as a more critical factor than social structure in fostering social integration.

However, as streets become scarce, they often conflict with their mobility purpose while reflecting their social functions. Streets epitomize the struggle to accommodate functions of "efficient" and "fast" but also "sustainable" mobility, as well as public space functions that include lingering and social interaction [38]. To address this challenge, Von Schönfeld and Bertolini [38] proposed recommendations at both the planning and governance levels. At the planning level, enabling more flexibility would allow public spaces in general and urban streets, in particular, to better adapt to changing roles. At the governance level, the involvement of residents and stakeholders in the street design process and the promotion of collaboration between the community and government are essential to achieve the desired outcomes.

3.2.2. Human-Centered Street Environment Design

The physical environment of the street influences street activities and even subtle environmental features significantly impact the experience of street users [23,39,40]. Urban design literature identifies human-centered qualities that enhance active travel, and these qualities act as a mediating factor between physical features and pedestrian behavior. In essence, to promote a sustainable transformation of urban space, understanding the public environment, including the street, as a combination of behavioral and physical environmental patterns is proven valuable.

Table 3. Articles examining the correlation between innovative street and urban livability.

IV: Street Activities to Enhance Social Interaction			
Reference	**Objectives**	**Factor(s) Examined**	**Results**
[35]	To enhance the value of the urban street as a social place.	• Route choice • Street aesthetics • Traffic and environmental safety • Diverse land use	• High-quality street environments such as convenient pavements and trails encourage residents to travel. • There will be a more pleasant social atmosphere and more aesthetically pleasing streets when there is less car traffic and less street incivility. • People are more attractive to people. Street users enjoy seeing people enjoying themselves, which enhances street communication.
[37]	To understand whether streets designed to be more livable encourage more diverse street users and activities.	• Home zones • Urban livability • Neighborhood streets • Shared space	• Different people use healthy streets for a variety of activities. • Well-designed streets will balance their competing requirements. • Streets with high design quality in home zones tend to be most friendly to children, where they are free to engage in activities. More adults will spend time here responding to the children and family. • Vibrant streets need to be permeable to pedestrians and bicyclists.
[34]	To discuss how street design and traffic affect social relations in urban neighborhoods.	• Social integration • Urban neighborhoods • Street livability • Traffic-calming	• The neighborhood streets are active social places. Streets with slow-moving traffic, limited space for parking, and good environmental qualities offer potential for personal development, contentment, and social inclusion. • The influence of the street structure, i.e., layout, speed limit, and design, is more important than that of the social structure. • The streets are great places for social integration, where children learn the language and where neighbors get into contact with each other.

Table 3. *Cont.*

IV: Street Activities to Enhance Social Interaction			
Reference	**Objectives**	**Factor(s) Examined**	**Results**
[38]	To clarify the significance of mobility functions and public space in urban streets for sustainable urban transition.	• Urban street • Social place-making • Urban mobility • Sustainable transition	• Mobility and public space are crucial elements determining the vitality of cities. • Enabling more flexibility would allow public spaces in general and urban streets, in particular, to better accommodate the various and shifting roles. • Governance takes the shape of participation, where different stakeholders are involved in decision-making processes. Participatory processes of planning have become imperative.
V: Human-Centered Street Environment Design			
Reference	**Objectives**	**Factor(s) Examined**	**Results**
[14,41]	These two studies address the relationship between social behavior and street environmental quality.	• User behavior • Physical street characteristics	• A high-quality street environment encompasses an adequate number of seating, pavement, street furniture, shade, and permeable and personalized street fronts that encourage people to congregate. • Street seating is conducive to pedestrians engaging in stationary activities. • Streets as public spaces create liveable • Rhoods; therefore, social, physical, and usage dimensions must be considered.
[40]	To analyze users' behavior in the street space and the interaction with physical street settings.	• Land use along the street • Street type • Users' behavior • Physical environment in streets	• Wide sidewalks, balconies, curbs, and street speed limits can improve walkability and accessibility. While multi-functions such as shopping malls, office blocks, and residential areas facilitate walkability. • Safety hazards are hidden in a high level of the walkable and pedestrianized area. Multi-street facilities and free access lead to street congestion. • To provide buffers between sidewalks and lanes, offering crosswalks could ensure street safety. • Safe connections between neighborhoods and special features should be considered to meet the basic needs of street users.
[23]	To propose flexible design principles for improving the flexibility of street furniture.	Standardization, suitability,adaptation, management, and safety of street furniture	• Community streets in urban areas suffer from excessive standardized street furniture, which cannot adapt to changing street conditions. • Urban characteristics and local identity are lost as a result of standardization. • Flexible street design principles are proposed: Custom in use, multifunctional use, respond effectively to changing circumstances, easy and conveniently managed, universal in use, and sustainable in use.

Table 3. *Cont.*

VI: Active Travel and Its Assessment Criteria			
Reference	**Objectives**	**Factor(s) Examined**	**Results**
[42]	To summarize the relationship between cycling and built environment characteristics.	• Cycling purpose • Built environment factors	• The presence of cycle paths and bike facilities was conducive to commuters and general cycling. • Mixed land use, availability of cycleways to non-residential destinations, and topographic gradient have less effect on cycling behavior in the urban context.
[43]	To offer visual assistance for identifying areas where modifications are required to enhance sustainable travel.	• Bicycle-route density • Bicycle-route separation • Topography	• A bikeability index was created to characterize and map a region's suitability for cycling, which can be applied for further research on health disparities referring to physical activities and urban street environments. • The index comprised five factors to positively influence cycling behavior: bicycle facility availability, bicycle facility quality; street connectivity; topography; and land use.
[44]	To outline a bicycle route choice model to advocate a better cycle-friendly street environment.	• Street infrastructure • Intersection control • Traffic signals • Bicycle lanes	• Cyclists are concerned with distance, frequency of turns, control of intersections, and traffic volumes; the presence of street-side cycle lanes, traffic calming measures, and high street connectivity are valued. • The treatment of intersection signals must be determined by the traffic volumes.
[15]	To evaluate walkability through GIS and street auditing indicators.	• Connectivity • Convenience • Comfortability • Conviviality • Conspicuousness • Coexistence • Commitment	• Mixed land use, high-density intersections, and well-connected streets are vital to boosting walking by reducing access distances. • Other modes of public travel offer more route choices and encourage active commuting. • It is important to involve stakeholders and decision-makers in selecting key concerns and avoid a simple additive equation of indicators.

The human-centered approach to street research focuses on user behavior, street area, and street facility. Gehl [36] claimed that dynamic and static pedestrian activity is a criterion for determining whether a street is human-centered. He suggested that the street's physical environment must provide static and mobile support. Mehta [41] argued that physical, land use, and social dimensions are critical in understanding urban streets to achieve human-centered streets conducive to stationary, lingering, and social activities Meanwhile, Do, Mori, and Nomura [40] classified resident behavior as accessibility, trading, idling, service, maintenance, and relaxation to examine the triadic relationship between user distribution, behavior, and the street physical environment in support of street management and social sustainability. By analyzing dense streets in Hong Kong, Siu and Wong [23] presented flexible street design principles, including custom in use, multifunctional use, responding effectively to changing circumstances, being quickly and conveniently managed, universal in use, and sustainable in use.

Human-centered street design characteristics (Table 4) are more than their physical components since they have a cumulative effect more remarkable than the sum of their parts [45].

Table 4. Human-centered street design approaches.

Elements	Theoretical Findings
Street width	• Wider streets increase evacuation capacity [46,47]. • Wider streets are suitable for integrating various modes of transport (e.g., bus or bicycle lanes, footpaths, etc.) [48]. • Less active transportation is expected along wide arterial roads that prioritize vehicle movements and do not provide adequate street tree protection [49].
Sidewalk	• Wider sidewalks can facilitate a variety of behaviors while also improving street connectivity and social interaction [40].
Seats	• Well-designed street seating is beneficial for walking [35]. • Ample seating is more beneficial for people when there are activities on the street [41]. • Seats are essential for pedestrians' stationary activities because people tend to sit most where there are places to sit [14,50].
Railings	• Fixed railings decrease the freedom of pedestrian movement [23].
Curbs	• Stationary activity occurs in places such as curbs, railings, and shaded areas [51]. • Metal and concrete railings are prone to secondary injuries after traffic accidents [23]. • Curbs bring more walkability and accessibility [40].
Street signage	• Adequate commercial signage is a distinctive feature of a pedestrianized street [39]. • Signage helps to create an area with high accessibility that is easy to enter and navigate [40].
Street green	• The shade produced by the street trees facilitates the gathering of street users [41]. • Trees, similar to other features, can play a central role in enhancing street livability [8,52]. • Street trees provide shade and reduce temperatures, which improves walking and thermal conditions [53].

3.2.3. Active Travel and Its Assessment Criteria

The street is inseparable from traffic, particularly active modes dominated by walking and cycling. Traditional research on street walkability is mainly based on field research combined with GIS data analysis. Measurement methods have become diverse owing to the accumulation of theory and technology development. According to the 3-Ds (density, diversity, design) for travel demand [54], Ewing and Handy [55,56] proposed the 5-Ds (density, diversity, design, distance to public transport, destination accessibility). Likewise, the 7-Cs criteria [15], i.e., connectivity, convenience, comfortability, conviviality, conspicuousness, coexistence, and commitment, were proposed based on the multidimensional 5-Cs (connected, convenient, comfortable, convivial, and conspicuous) by London Planning Advisory Committee [57]. The 7-Cs is a collection of the neighborhood and street-level variables that overlap substantially with the D-variables. Common findings indicated that mixed land use, high-density intersections, and well-connected streets are crucial to boosting walking by reducing access distances [15,54].

The measurement of street walkability has developed a robust framework, yet there are limited tools for evaluating a bicycle-friendly street environment. Broach, Dill and Gliebe [44] presented a demand model and route-finding tool for predicting bicycle travel based on GPS data. They found that cyclists are sensitive to distance, turning frequency, gradient, junction control, and traffic volume. Enhanced community bike lanes with traffic calming measures promote cycling volumes. Winters, Brauer, Setton, and Teschke [43] classified measuring techniques into five categories: cycling facility availability, bicycle facility quality, street connectivity, topography, and land use. The flexible parameters and weighting scheme of the approach enable users in other cities to modify it to their specific circumstances.

Additionally, conflicts exist between walking and cycling in the configuration of street space [42]. The heterogeneous street environments created by a mix of land uses may be conducive to walking, which may negatively impact the speed and safety of cyclists. Bicycle sharing stations often conflict by taking up pedestrian lanes and squeezing blind spaces. Further investigation is needed to examine the impact of modifications to the built environment of streets on active transportation and the mitigation of potential spatial conflicts between walking and cycling.

4. Discussion

4.1. Synergies and Potential Conflicts

The synergistic effect of urban mobility on livability encompasses the following elements: (1) A safe street environment is a prerequisite for community interaction to occur. Traffic calming measures and slower travel speeds encourage increased street activity and safety, which allows for greater visibility and mobility for pedestrians and cyclists; (2) street buffers enhance neighborhood safety by increasing pedestrian traffic and social interaction. Street buffers refer to physical separations between sidewalks, roadways, bike lanes, and waiting areas at intersections; (3) smart urban infrastructure and green traffic patterns result in an attractive street environment. Use electric and low-emission transportation modes to reduce urban air pollution and community noise pollution; (4) street hierarchy is central to the design and management of urban street networks. A multi-level urban street network formed by the combination of fine orthogonal grids and multiple sets of radiations maintains the high-connectivity advantage and responds to the diverse demands of daily life; (5) the integration of diverse modes of public transportation, including metro systems, public buses, bike-sharing programs, and car-sharing services, is essential in enhancing street accessibility and fostering incidental encounters. The availability of multiple travel options promotes socialization and provides individuals with greater flexibility and independence in navigating the city.

Urban livability and mobility are interdependent, impacting the other in significant ways. Regarding enhancing urban mobility, urban livability works in the following ways: (1) Vibrant streets encourage active travel behaviors. Human activity is attractive to others [36]. Individuals are more likely to choose walking when there is a presence of social interaction or recreational activities in the street environment; (2) the presence of street activities also helps to improve safety through a reduction in vehicle speeds. Drivers slow down when there are more pedestrians and activities on the street based on their perception of the street environment [28]; (3) frequent street activities catalyze the construction of shared facilities, such as bike-sharing. The provision of these facilities meets the commuting and social needs of participants, promoting a more livable and sustainable urban environment.

Mobility patterns and public space usage are inextricably linked since rising mobility and more intensive use of public space feed off one another and directly compete for ever-scarcer urban space. They exemplify the competition to balance "efficient" and "fast" mobility functions with public space activities such as lingering and social interaction [38], which is reflected in roadways, on-street parking, physical street separation, and street activities as follows:

(1) Reducing the number and width of roadways for safer neighborhood intersections results in lower travel speeds, but also exacerbates traffic congestion. The compression of lane space leads to increased crossing times for drivers and waiting times for pedestrians, diminishing the efficiency of street mobility.
(2) While low speeds in on-street parking can improve street safety, it can also contribute to urban congestion [40]. The presence of parking automobiles might interfere with moving vehicles and passing pedestrians by obstructing the view of each other from the driver and pedestrian [13,17,58]. Unexpected "dooring" during on-street parking threatens cyclists and pedestrians [13].
(3) Physical separation improves street livability and accessibility by providing a comfortable passing experience for walkers and cyclists. Nevertheless, when high traffic volumes come, separated strips can decrease commuter efficiency as the space occupied by the separation could have been utilized for additional transportation lanes [58].

4.2. Recommendations for Designing Innovative Streets

We advocate for innovative street design strategies to create sustainable and livable urban environments. These strategies are critical for making urban spaces more accessible, safe, sustainable, and socially engaging. By implementing these approaches, urban streets can prioritize people over cars, encourage sustainable mobility, and ultimately enhance the quality of life for residents.

4.2.1. Smart Street Infrastructure

Installing smart street amenities such as smart parking, charging stations, and citywide WiFi is highly recommended to enhance the experience of both drivers and pedestrians, making urban streets more convenient and user-friendly. Developing smartphone applications that utilize car GPS to provide real-time updates on parking availability at street intersections is another effective way to increase convenience and reduce traffic congestion. Such applications can help drivers easily locate parking spots, saving time and energy. To promote sustainable transportation, it is also recommended to increase the number of shared urban bicycles with fixed sharing points, encouraging more people to use bicycles for daily commuting and reducing traffic congestion. These measures support the transition to sustainable mobility, reducing carbon emissions and promoting a more sustainable transportation system.

4.2.2. Hierarchical Street Network

To improve street connectivity, grid network patterns without barriers and hierarchical dendritic patterns are recommended. Compared to dendritic networks, grid networks are less susceptible to potential disruptions in certain parts of the street. Additionally, it is suggested to reform the dendritic pattern to improve its connectivity by adding pedestrian/bicycle lanes to connect dead-end roads to other streets in the network. Increasing redundant connections in the street network is also encouraged to provide accessibility of service. Furthermore, promoting mixed-use development around highly concentrated street nodes/connections is an effective way to increase the vibrancy of the area. Appropriate pedestrian space reductions on centrally placed and pedestrianized streets could be transformed into one-way access for automobiles, enhancing car access to pedestrian zones and overall traffic efficiency.

4.2.3. Safe Streets as a Guarantee of Access

In urban district bureaus with high residential density, it is essential to prioritize pedestrian safety and comfort. One effective way to achieve this is by ensuring that sidewalks are as wide as possible and provided on both sides of the street. Additionally, distinguishing bike lanes from motorways through the use of white lines or broader buffer strips can increase safety for cyclists. To further improve safety, it is recommended to eliminate on-street parking space close to the intersection. This ensures that drivers and cyclists are visible to each other, reducing the risk of accidents. Mitigating turning conflicts at intersections can be achieved through the use of mixing zones, signal-protected turns, offset crossings, or bicycle-only waiting zones. Allocating space for communities or transport can also be achieved through reducing lane widths or removing under-utilized lanes. Lighting is another crucial aspect of street design that significantly affects safety and comfort. Therefore, improving the overall lighting environment of the street with street lights fixed to the appropriate building façade can significantly enhance pedestrian safety. To ensure safety and order at intersections, "corner quadrants" can be set up. Only elements related to safety, lighting, and traffic control infrastructure can be sited within the corner quadrant.

4.2.4. Street Activities to Enhance Social Interaction

In order to enhance the pedestrian experience and encourage social interaction, it is essential to provide adequate supportive facilities and equipment. The provision of public recreational amenities such as benches and railings should be determined based on the function and spatial capacity of the street. Additional seating should be made available to allow crowds to sit together and engage in various forms of social interaction. Shade and shelter, as well as street greenery, play a vital role in determining pedestrian activity levels. These amenities can provide a respite from the sun, rain, and wind, and also create a more pleasant environment for pedestrians. Additionally, the street hierarchy is another critical factor in promoting pedestrian interaction. Primary and secondary street pedestrian spaces should be supplied with a diverse range of street amenities that cater to different scales of activity. A tailored approach that considers the specific needs of each street should be taken, with amenities designed to complement the function and character of the street.

4.2.5. Human-Centered Street Environment Design

Improving human-centered street environment design is a crucial component of creating livable and sustainable urban environments. One key consideration is the appropriate buffer width between traffic lanes, which should be scaled based on the volume of traffic and condition of the street. On residential streets with lower traffic volumes, narrow buffers are adequate. However, for streets with higher motor vehicle speeds and volumes, wider buffers are necessary. Another important factor to consider is the street width. Appropriate street widths play a critical role in facilitating evacuation, creating multi-modal streets, accommodating technological transitions, and adapting to changing conditions. Calculating the right width involves considering the geometry of the street canyon, such as the aspect ratio, and the population density of the community. Modifying street edges through streetscape improvements is also crucial to ensuring that streets serve transportation, accessibility, and socioeconomic purposes. For instance, streetscape improvements can help increase the permeability of the street façade and create a visually appealing and welcoming environment for pedestrians and cyclists. Enhancing visual and physical openness and continuity between interior and exterior spaces can also help to create a sense of community and belonging among residents.

4.2.6. Active Travel Behavior

To improve mobility and reduce reliance on personal vehicles, it is important to increase the number and quality of transport modes available to residents. This includes not only buses and subways, but also shared bicycles and vehicles. By promoting alternative modes of transportation, cities can reduce congestion and air pollution while also providing greater access to key destinations throughout the urban landscape. In addition to expanding transportation options, it is also critical to design physical separations between the carriageway and the bicycle lane. This helps to improve safety for cyclists and reduce the risk of accidents. By providing dedicated cycling infrastructure that is separated from vehicular traffic, cities can encourage more people to bike for transportation, recreation, and exercise. Furthermore, creating accessible infrastructure is another key consideration in enhancing street inclusion. This includes the addition of handrails, accessible ramps, and Braille signs, among other features. By making streets more accessible to people of all abilities, cities can promote a more inclusive and equitable environment for everyone.

4.3. Principles for Further Research

Developing research guidelines facilitate theoretical development for innovative streets and sustainable urban transitions. The following principles provide further illumination for street studies.

First, streets should be identified as places for access, commerce, leisure, activity, and socialization. The structure and capacity make the street a complex public space with the attributes of both transportation and social functions. Accordingly, addressing urban mobility and other physical characteristics alone is inadequate if the social and economic role of the street is overlooked. A limited body of literature focuses exclusively on the social features of streets and their relationships with urban dwellers without adequate consideration of their transit capacity. In this respect, this review stresses the importance of having the multiple identities of the street recognized simultaneously, as their transportation characteristics contribute to a higher level of urban efficiency and safety. In contrast, their social characteristics contribute to enhanced neighborhoods and increased social activity. Developing a balanced approach to mobility and livability within a limited street area will contribute to a sustainable urban transition.

Second, policymakers and urban planners should recognize that street users make their behavioral judgments, which may result in deviations between expected planning results and street reality. Equally, users tend to choose active street environments that are positive for them as places to socialize and reflect the same tendency when choosing transportation routes.

Third, the importance of considering users of all ages and abilities cannot be overemphasized. An active pedestrian environment for healthy adults may be poor or even inaccessible to seniors or the disabled [14,15]. The street is a public space for all citizens, not exclusive to specific users. As a public space that serves all citizens, the street must offer diverse and flexible functions and comprehensive amenities to accommodate the needs of a wide range of users. Hence, research on streets, neighborhoods, and livable cities must prioritize increasing the diversity of neighborhoods and demographic samples under examination.

Fourth, the development of assessment systems needs to be transformed into a supportive tool for participatory decisions. This necessitates the participation of stakeholders, decision-makers, planning authorities, and street users in selecting key questions and weighing indicators to prevent simple additive equations. The assessment system should be closely aligned with practical applications to guide design practice.

4.4. Limitations

This paper has several limitations that should be acknowledged. Firstly, the paper has not been able to provide an in-depth analysis of the various types of urban streets. Pedestrian streets, traffic arterials, and neighborhood streets all serve different purposes in the urban system. It is essential to conduct further research that examines the nuances of different types of urban streets and their specific roles in varying urban contexts. Secondly, the methodological search filter we used has restricted our ability to comment on a broad range of articles. Our analysis has focused on 24 key articles that were primarily quantitative in nature and based on data acquired from major cities in developed countries. Therefore, the study lacks attention to small and medium-sized cities as well as cities that are relatively lagging in development. Thirdly, while the study does touch on important social and mobility-related identities associated with urban streets, it does not explore other aspects such as ecological resilience that contribute to sustainable urban development. Future research should aim to examine a wider range of factors that contribute to the identity and role of urban streets in shaping urban environments.

5. Conclusions and Further Directions

This review critically evaluates key articles in the field of innovative urban streets using rigorous selection criteria and provides a comprehensive discussion of their specific contributions to urban sustainability. While previous studies have tended to focus on single characteristics of urban streets, our review proposed a novel approach by linking mechanisms that promote the social attributes of streets with the design of features that facilitate efficient commuting. Our analysis of the intricate identities of urban streets and our approach to bridging conflicts resulting from these diverse identities marks a significant breakthrough that sets our work apart from existing studies. Building upon this foundation, we proposed a suite of innovative design methods and principles for urban streets, including measures to enhance street safety, an all-age consideration principle, a reality-aligned decision-making approach, and a participatory approach to decision-making that offers concrete design guidelines.

The ultimate goal of this study is to achieve sustainable urban development by constructing innovative urban streets, which align with the United Nations' Sustainable Development Goals. Specifically, the social attributes of streets can foster neighborhood communication and improve residents' mental health, contributing to the goal of "good health and well-being". The identification of smart street infrastructure, promotion of hierarchical streets and transportation integration fall within the scope of the goal of "industry, innovation, and infrastructure". Furthermore, the discussion of the synergies between urban streets in terms of livability and mobility, and the proposed recommendations for designing safe street environments, can enhance the construction of "sustainable cities and communities".

In light of the theoretical debate over the identity of streets, i.e., streets as transportation routes or social places? This review posits that streets serve both transportation and social purposes, evolving into places for community, political, economic, and cultural activities. In today's increasingly competitive street space, street efficiency and vitality can be strengthened by developing the synergy of urban mobility and livability instead of enlarging the conflicts. It is worth emphasizing that the social characteristics of streets are frequently expressed through users' behaviors; therefore, studying street-neighborhood relations necessitates an examination of the relationship between users' behavior and street space. In establishing evaluation systems for streets and street users, stakeholders, decision-makers, and participants must be involved in weighting key concerns and indicators to avoid simple additive equations. Moreover, the review highlights the need for streets to be accessible and equitable public spaces for all citizens, particularly considering the needs of elderly and disabled populations in the design process.

Regarding future directions, technological solutions are collaborating to build smart cities. With the emergence of these technologies, IoT devices are becoming increasingly visible on city streets. Through smart street structures, the IoT can transmit real-time traffic information and effectively control street lighting, traffic systems, and automatic navigation systems. These smart devices and analytics can assist with city management and the decision-making process. In terms of research methodology, it can be challenging to establish cause–effect relationships in a cross-sectional approach. Considering the deviation of design ideals from the expected values of the street and the delays brought on by implementation, follow-up, and longitudinal studies will provide more comprehensive insights into the effects of creative design tools. Additionally, streets have multiple identities due to the different types of streets and complex urban context. Further research must expand on the findings of this paper to carefully evaluate different types of streets and specific cultural and geographical environments, in order to provide significant assurance for street design in sustainable urban development.

In conclusion, the innovative street design methods and planning principles have the potential to make a significant contribution to sustainable urban transformation, particularly in terms of enhancing urban mobility and livability. A collaborative effort between urban planning and street space research is essential. This partnership can help to create efficient and livable urban public spaces that meet the diverse needs of urban residents. Predictive street concepts and practices serve as a valuable tool for planners and policy makers in making sustainable policy decisions. By incorporating these concepts, cities can design streets that prioritize the needs of pedestrians and cyclists, while also improving access to public transportation and reducing dependence on private cars. In addition, designing innovative streets requires the incorporation of a range of elements, such as diverse land uses, residential design, highway design, and architectural design. By considering these elements, cities can create environments that promote physical activity, social interaction, and community engagement. Ultimately, by prioritizing the creation of sustainable and livable urban streets and environments, cities can ensure the well-being of their citizens for generations to come.

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