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SMART INFRASTRUCTURE RESEARCH: A REVIEW AND AGENDA FOR ADVANCING SUSTAINABLE URBAN DEVELOPMENT

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Abstract

Accelerating urbanization, climate and environmental challenges, and resource constraints make sustainable development imperative. Smart cities are a mechanism for sustainable urban development, and smart infrastructure is key to achieving this mechanism. This study explored the key role of smart infrastructure in promoting sustainable development in urban areas. Despite the increasing academic attention in this field, a comprehensive assessment of the correlation between smart infrastructure and urban growth remains lacking. This study obtained 77 papers published in the Scopus and Web of Science databases from 2018 to 2024 using keyword searches. After careful screening using the SPAR-4-SLR protocol, 22 representative publications related to this topic were obtained. A systematic literature review was conducted using bibliometric analysis to identify and illustrate the important topics, technologies, and trends. This study also combined the Antecedents, Decisions, Outcomes (ADO), and Theory, Context, and Method (TCM) frameworks to study the determinants of smart infrastructure development. The results show that smart infrastructure is essential for addressing issues such as urban population expansion, climate change, and resource constraints in cities. This study outlines the current status and main trends in smart infrastructure research, highlights areas for future research, and emphasizes the need for interdisciplinary collaboration, technological innovation, and policy support to enhance the impact of smart infrastructure on sustainable urban development.

Keywords: ADO-TCM, Digital Transformation, Framework, Smart Cities, Smart Infrastructure, Sustainable Urbanization.

1. Introduction

In 2015, the United Nations released a worldwide plan for sustainable progress, known as the 2030 Agenda for Sustainable Development, with 17 goals [1, 2]. The focus on cities is twofold: Goal 9, building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation, is reflected in the development of high-quality, reliable, sustainable, and resilient infrastructure; goal11, is inclusive, safe, resilient, and sustainable cities, and human settlements, is reflected in creating urban areas and communities that are welcoming, secure, adaptable, and environmentally conscious, which is expressed in the goal of achieving the following by the year 2030. Enhancing the abilities for collaborative, holistic, and long-lasting urban development planning and administration through the promotion of inclusive and sustainable cities across all nations. (Transforming Our World: Sustainable Development Plan, 2030). The capacity of local systems to maintain human well-being, known as sustainable urban development, is intricately linked to resilience [3].

It is necessary to mention another related research hotspot: Smart City. “Smart city”? In a 2018 study, it was noted that the United Nations (U.N.) did not have a clear “smart city concept” because it was still evolving. The U.N. cultural agenda calls for cities to be more "inclusive, safe, resilient, and sustainable" [4]. Hundreds of smart city projects are currently being developed globally. Most smart city definitions emphasize infrastructure, concentrating on the deployment and ongoing operation of networked sensors and data analysis systems [5]. Smart Cities are an important tool for sustainable urban development and integrating sustainable practices into urban planning [6].

From this perspective, infrastructure development is inextricably linked to sustainable city-building. Infrastructure systems are widely recognized as the lifeblood of communities and play a critical role in maintaining economic prosperity, urban resilience, and sustainability [7]. Some scholars suggest that smart city infrastructure is the first step in establishing an overall smart city framework and architecture [4]. In the construction and development of smart cities, the construction of smart infrastructure is particularly important, and at the same time, the construction of smart infrastructure is also a crucial part of sustainable urban development [8]. Smart infrastructure is a rapidly evolving field, and research in this area involves a multidisciplinary cross-section of technical, social, economic, and environmental aspects.

A review of smart infrastructure is necessary at this stage of the study. First, an initial search of WOS and SCOPUS showed that a large amount of research already exists in the field (more than 1,100 closely related articles have been published), the field has reached a sufficient level of maturity for review, and there have been very few comprehensive reviews after 2018. Therefore, a comprehensive systematic literature review is required to provide a systematic overview of the field [9]. Second, after further screening, the review from the perspective of “smart city building” yielded only 22 articles for review, suggesting that the field is in its infancy or of little interest to researchers and that systematic literature reviews are needed to stimulate more research in the field. Third, two recent articles on the methodology of the review, published by Paul et al., provide a state-of-the-art knowledge base for domain reviews, establish a set of standards for reviewing domains, and provide a range of techniques, methods, procedures, protocols, and terminology.

Based on the above problem statement, this study presents a bibliometric analysis of smart infrastructure from the perspective of sustainable urban development using the following three agendas for a systematic review:

(1) What is the status of smart infrastructure development?

(2) How does the ADO-TCM framework reveal that smart infrastructure plays a critical role in the sustainable urban development of smart cities?

(3) What are the trends in smart infrastructure and areas for further research?

Conducting a systematic literature review of smart infrastructure not only deepens research in the academic field but also provides theoretical support for practical applications, promotes technological innovation and interdisciplinary cooperation, and solves practical problems in the development of smart infrastructure.

This study utilized the SPAR-4-SLR protocol framework to conduct a systematic literature review, which outlines the scientific procedures and rationale for these reviews. Scholars conducting systematic literature reviews rely on the PRISMA protocol; nevertheless, studies have indicated that these evaluations were created for broad systematic assessments and offer minimal justification that scholars can use to support their evaluation choices. As an alternative, the SPAR-4-SLR protocol can be employed to provide such an understanding, and the plan will be thoroughly justified based on logical and pragmatic fundamentals; ii. be transparently reported according to the phases and subphases [10]. This study introduces the theories, contexts, and methods (TCM) used to gain this understanding using a new theoretical framework and provides a structured retrospective view of the antecedents, decisions, and outcomes (ADO) of smart infrastructure development in the smart city building process [11].

This paper comprises five sections. Section 2 describes the research methodology, and Section 3 provides detailed information on the data, beginning with a literature review of smart infrastructure from the perspective of smart city development. The detailed findings are presented and discussed in the following sections. Section 4 discusses the future prospects of this study. Section 5 discusses the limitations of the study.

2. Method

2.1. A framework for conducting methodical literature analyses: The SPAR-4-SLR protocol

A review protocol titled 'Scientific Procedures and Rationale for Systematic Literature Reviews' (SPAR-4-SLR) was published in the inaugural Special Issue on Systematic Literature Reviews. This protocol serves as an introductory piece aimed at furthering our understanding of systematic literature reviews. The protocol consisted of three phases and six sequential flow subphases (Fig. 1).

2.2. Bibliometric analysis

In recent years, bibliometric analysis methods have become more widely used in research, not only because of the development of software such as VOSviewer, CiteSpace, and R-tools, but also because of the increased accessibility of scientific databases such as Scopus and Web of Science. Techniques for bibliometric analysis can be divided into two main groups: analysis of performance, and ii—mapping the scientific data. The former is essentially a descriptive analysis that combines scientific mapping with the latter to analyse the relationships between study components to enhance the understanding of the comprehensiveness and completeness of the field under study [12]. In summary, this study adopts such an approach to precisely understand a large amount of unstructured data, broadening the depth and breadth of research on this topic [13].

2.3. The integrated ADO-TCM framework, which stands for antecedents, decisions, and outcomes-theories, contexts, and methods

A systematic literature review can take many forms, including domains, theories, and methods [14]. This study is a domain-based review that synthesizes and expands the large body of literature in the same substantive area. Paul et al. [10] further stated that it is recommended to use a combination of frameworks such as ADO and TCM to construct a systematic literature review, considering that the ADO framework alone cannot explain theories, contexts, or methodologies that can guide future research and may not be sufficient to do so and that TCM, as a good framework, can be used in conjunction with ADO to advance future research in this area [15]. Therefore, an integrated ADO-TCM framework was employed in this study. Such structural approaches can enhance authors' ability to provide maximum clarity and comprehensive coverage (in terms of scope and detail), making reviews based on these frameworks more valuable and influential.

3. Results and Discussion

3.1. Systematic literature review protocol and data sources

The SPAR-4-SLR procedure consists of three phases: assembly, alignment, and evaluation. The process was subsequently divided into six distinct stages: recognition, procurement, systematization, refinement, assessment, and documentation. These subphases are explored in the following sections and are illustrated in Fig. 1.

The initial search was conducted using the Scopus and Web of Science databases because of their extensive coverage [16]. EndNote was used to filter out duplicate documents to avoid multiple databases offering the same information. To obtain a large number of papers, an extensive search was first carried out with the proper Boolean operators and keywords: Period: 2018-2024; Language: English; Type= “Article” OR “Review”; Source= “Journal”; Subject Category= “Engineering” Before 2017, there was only one comprehensive review article on smart infrastructure with a broad concept; therefore, the year limit was set to 2018-2024. Select “Article” or “Review” as the document type as They offer the most reliable and significant information sources [11]. Reviews of books, presentations, discussions, and seminar papers were not included in this investigation and the language was limited to English.

A preliminary search yielded 1,119 articles on smart infrastructure, covering multiple fields such as transportation, energy, and agriculture. Since the scope of this study was limited to cities, keywords such as "city" or "metropolis" were added to screen out 77 articles. After removing duplicates, the number was reduced to 56. To minimize bias, the abstracts and content of each article were reviewed by the research team members and screened according to their relevance to the research question (RQ). This step eliminated articles with weak relevance, ultimately producing 22 relevant papers. Table 1 and Fig. 1 show the article selection process, from the initial screening to the final selection of articles.

Table 1. Search strings used in the literature review.

Sources	Search string
Scopus	TITLE-ABS-KEY (“smart infrastructure”) AND TITLE-ABS-KEY (and urban or city OR engineering OR article OR review) AND LANGUAGE (English) AND YEAR (2018-2024)
Web of Science	TS = (“smart infrastructure” and (“urban” or “city”)) AND ((construction OR construction industry OR building OR architecture OR engineering OR article OR review) AND LANGUAGE: (English)AND YEAR (2018-2024)

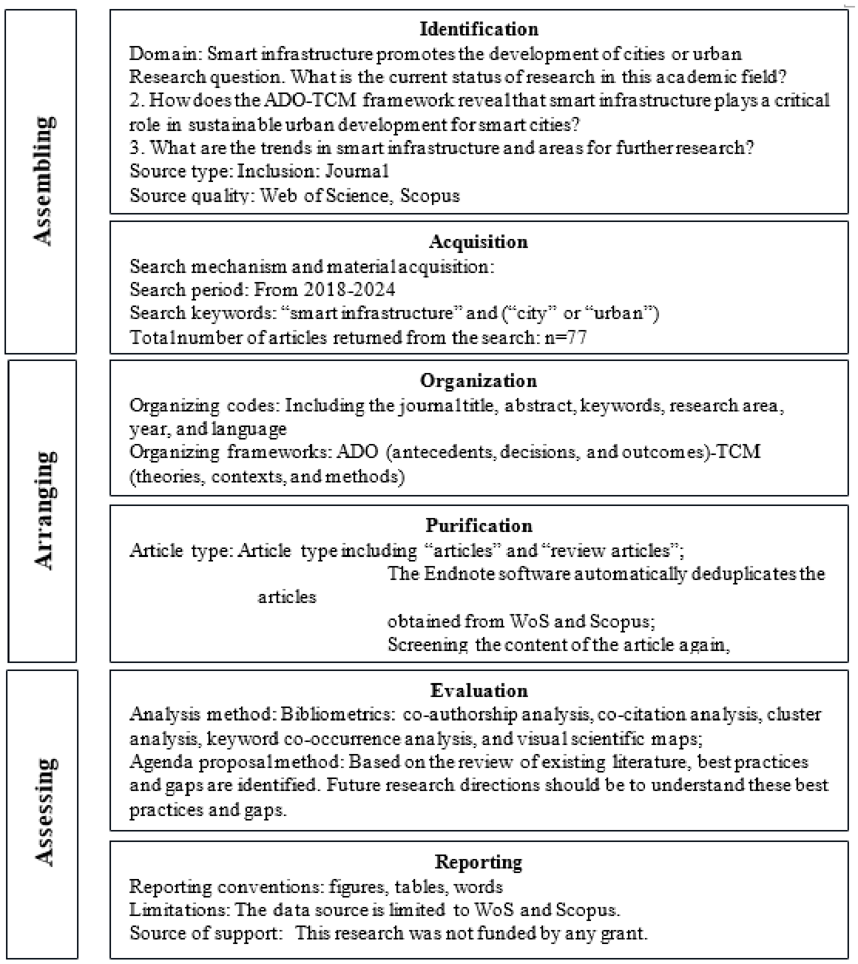

Fig. 1. SPAR-4-SLR protocol.

3.2. General descriptive statistics and visual analysis of bibliometrics

The annual number of publications (Fig. 2). Based on the number of publications per year, the trend of publications on the studied topic of smart infrastructure is plotted on a line graph as follows: It can be seen that since the development of its research up to 2018, the number of articles published in that year was small, indicating that the research topic was still in an emerging stage at that time and was not widely studied; there was even a decreasing trend by 2019. From 2020 onwards, the number of articles increased, indicating that researchers began to gradually pay attention to this field, and research interest increased, and then remained in a period of calm development. Until 2023, the number of articles has grown significantly, and research activity has become active, reaching its peak in these years.

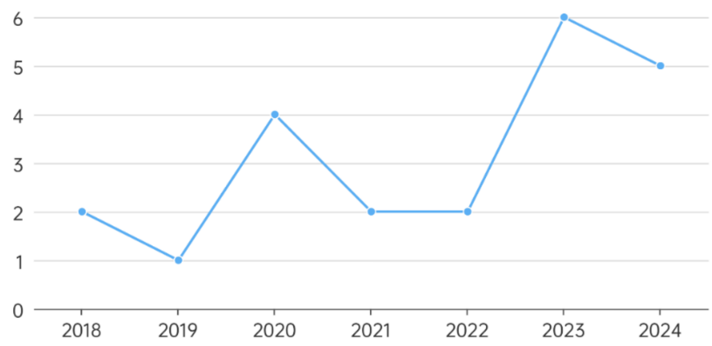

Fig. 2. Trends in Smart Infrastructure: An Annual Publication. (From 2018 to 2024.)

This Co-occurrence Network diagram illustrates the relationships between key terms and concepts in the research field of "smart infrastructure" to reveal the linkages between research themes and the structure of the research area [17]. Each node in the graph represents a keyword or concept, such as "sustainable", "urban", or "technology". The lines between nodes indicate the co-occurrence of keywords in the text. The thicker the line, the higher the frequency of co-occurrence, indicating that these two concepts often appear together in smart infrastructure research. Several node groups were clustered. Each cluster represents a subtheme or research area in smart infrastructure research [18].

As shown in Fig. 3, the keywords are related to technology (e.g., "IoT", "blockchain"), application (e.g., "management", "Services"), and goal (e.g., "sustainable", "smart"), suggesting that smart infrastructure is an important part of the infrastructure, applications, and goals, suggesting that smart infrastructures are an important part of a study covering a wide range of topics. Excluding the search terms smart infrastructure and city, nodes such as data, management, technology, sustainability, PPP, service, and systems represent research hotspots, suggesting that they are among the most active research topics in smart infrastructure (over time, some keywords may become more centralized, certain keywords may become more centralized and reflect a shift in research focus) [13]. The co-occurrence network diagram of smart infrastructure shows the intersection of multiple disciplines such as "civil"), environmental science ("environment"), information technology ("internet"), and information technology (Internet). The interdisciplinary nature of smart infrastructure research is an important feature.

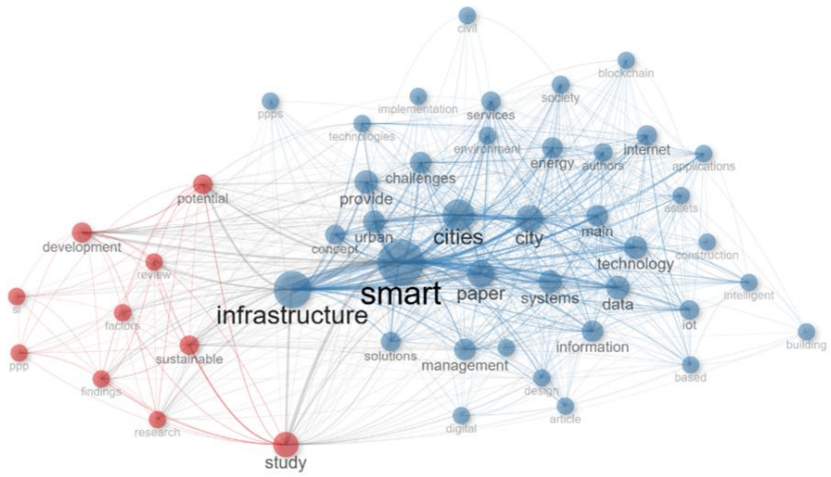

Fig. 3. Co-occurrence network.

Sankey diagram (Fig. 4). This diagram shows a systematic picture of smart infrastructure research in the field of smart city research, where the left side represents the situation of the sources being applied, the centre represents the keyword data, and the right side represents literature sources. Through the cited sources used as the basis of research, their concepts and methods were adopted and developed by subsequent research (the research topics are represented by the keywords in the middle). The results continue through new academic papers (sources on the right side), forming a dynamic process of academic knowledge accumulation and innovation that explains the path of research evolution in the field of smart infrastructure.

The width of the arrows in the chart represents the size of the arcs, which not only represents the influence of journals in a particular field but also identifies research hotspots by analysing the keyword traffic. After the initial search is excluded, it can be seen that the top research hotspots are digital technology topics such as 5G, AI, blockchain, and other topics, as well as sustainability topics such as carbon emissions, historical heritage, and asset management, and their related research has recently gained significant attention. The topics of 5G, AI, blockchain, and sustainability, such as carbon emissions, historical heritage, and asset management, have attracted a high level of interest in recent research.

This distribution shows the multidimensionality and interdisciplinarity of academic research. For example, the theme of "smart infrastructure" has strong links with journals such as the IEEE Internet of Things" and "IEEE Trans. Intelligent Transportation Systems," which indicates that research on smart infrastructure may have significant publications in the fields of the Internet of Things and intelligent transportation systems. This suggests that research on intelligent infrastructure may have significant publications in the fields of the Internet of Things and Intelligent Transportation Systems; "artificial intelligence" may intersect with "autonomy", "asset management", and other topics, which suggests that AI is applied in a variety of fields. Intelligent infrastructure, as an interdisciplinary field, involves a number of disciplines, such as urban planning, information technology, and environmental science.

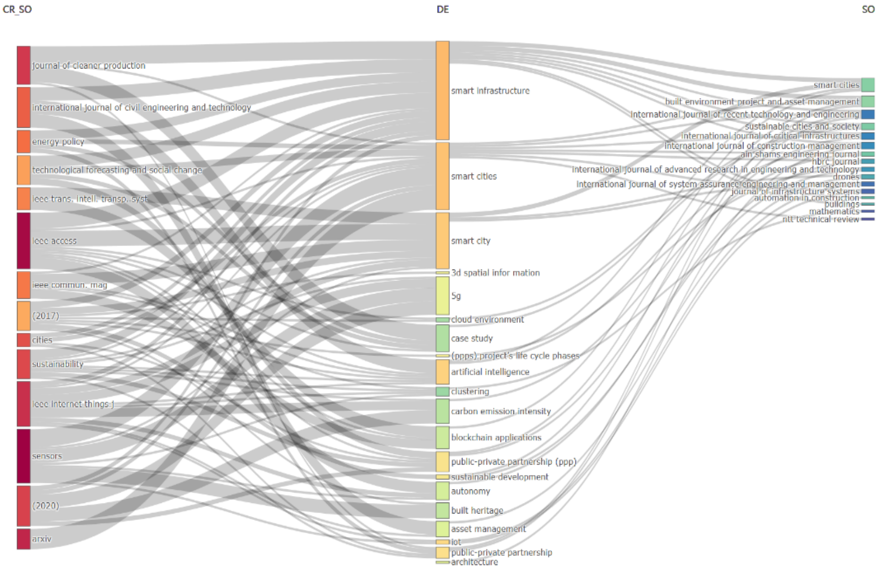

Fig. 4. Cited sources -keywords-sources Sankey diagram.

3.3. Analysis based on the integrated ADO-TCM framework

3.3.1. Antecedents, decisions, outcomes

The factors that influence whether someone chooses to perform or avoid a particular action are encompassed by these antecedents. Consequently, they can directly affect decision-making processes or indirectly influence the resulting outcomes [11]. In this review, the antecedents that promote smart infrastructure are grouped into four categories: government, environment, technology, and society. Choices are linked to whether actions are taken, functioning as a direct consequence of the preceding factors and a forerunner of the results [9].

First, government-related antecedents summarize the factors that may affect the development of smart infrastructure, stemming from government policy planning for urban development. Rapid urbanization driven by economic development has led to several related issues: population growth, pressure on the environment due to limited resource constraints, and the transformation of industries towards smart development. The emergence of these problems has intensified the demand for sustainable urban development, in addition to responding to climate change, extreme weather, and earthquakes. Additionally, there are societal and cultural requirements, including enhancing the population's standard of living, upgrading government service delivery, and safeguarding the city's historical landmarks. Urban development should be more resilient and sustainable, and smart cities should be enabling tools for sustainable urban development. The development of smart infrastructure is a prerequisite for the development of smart cities.

Second, large-scale development requires adequate budgets, and the lack of public funding has forced governments to seek innovative solutions [19]. The feasibility of the public-private partnership (PPP) model to solve the financing problem was suggested in a study as early as 2018, which proposed a PPP modelling framework [1]. This innovative research has led to significant advancements in this field. Selim and ElGohary [20] clarified that stakeholders are key factors in the success of PPP projects and proposed a stakeholder role matrix and PPP project lifecycle stages. Jayasena et al. [19] found that PPPs can be effective in reducing government budgetary pressures, facilitating efficient project management, and capitalizing on private sector innovations. However, the study also points out obstacles such as public scepticism towards private sector participation in infrastructure development, inadequate policies and regulations, unsatisfactory financial structure, and political instability. Ultimately, this study proposes a basic framework for the Hong Kong region to follow in the future implementation of PPP for smart infrastructure projects.

Third, technological progress in digital systems, including AI, IoT, unmanned aerial vehicles (UAVs), and blockchain technology, provides a foundation for implementing smart infrastructure. IoT technologies improve monitoring and protection efficiency, whereas cost-effective monitoring technologies enable real-time data collection [21]. There are two aspects to everything, and the generation of large amounts of data has made cybersecurity and data security key considerations in designing smart infrastructure. Blockchain technology can be used to improve the transparency and security of smart city infrastructure, improve city management and services, and increase the efficiency and sustainability of resource management [22].

Fourth, the social reasons for building smart infrastructure include improving the quality of public services, promoting social equity, and meeting the challenges of rapid urban development [23]. The need to improve the efficiency of resource use and the quality of life of the population also contributes to the development of smart infrastructure to optimize urban management and services [24].

Owing to the needs of the antecedents, the related research decisions involved are mainly divided into several aspects: the development and creation of frameworks and platforms, such as DaaS frameworks, PPP platforms, designing real-time data collection and analysis platforms, and smart infrastructure management platforms, and the introduction of hot digital technologies into the construction of smart infrastructure, such as the introduction of the hybrid strategy HIHCS and AROS to optimize IoT performance, building UAVs in smart city intelligent traffic dynamic control infrastructure, using SMS multimode fibre-optic sensors to monitor infrastructure strain and vibration, and introducing blockchain technology to guarantee data security. More in-depth is the application of innovative algorithms; for example, the introduction of a 3D inspection algorithm to smart infrastructure and the use of the CycleGAN algorithm to ensure smart city security. The convergence and amalgamation of various disciplines have intensified the demand for intelligent management of urban infrastructure and city environments. The implementation of standardization for asset management is also proposed in this study [25].

Outcomes are assessments that occur after the execution or non-execution of actions [11]. After conducting research based on the above decisions, the final research results showed that, the new systems developed in smart infrastructure development for real-time data collection and analysis enable more effective monitoring and management of energy use and emissions, promote the sustainable use of resources, proactively address the challenges of climate change, and improve the resilience of cities in the face of natural disasters and other emergencies. The smart infrastructure was validated to improve ecological outcomes.

Most of the research conducted is unilateral, such as the monitoring of traffic conditions, layout of sensors and surveillance equipment, and high-precision 3D spatial information frequency stations. Future research could consider how to improve urban resilience through the establishment of an integrated disaster early warning and emergency management system and an intelligent emergency command system that integrates multi-sectoral information to improve the speed and efficiency of response to natural disasters and emergencies. In addition, existing research has pointed out that over-reliance on smart technologies may lead to a waste of resources and an increased burden on the environment [26]. Future studies could attempt to expand and explore this perspective.

The proposed model for the holistic management of assets [25] and the Smart PPP modelling framework were identified, evaluated, and validated [19]. The study shows that by introducing private capital, the government can reduce its direct investment in large infrastructure projects, make more effective use of limited public funds, and ease fiscal pressures. Future research could review PPP-related policies, cases, and implementation results and explore the contribution of PPP models to the realization of sustainable urban development goals by integrating economic, environmental, and social benefits. It validates the support of several advanced digital technologies for the construction of smart infrastructure, analyses a large amount of collected data to provide a scientific basis for smart city management and policy formulation, and promotes more accurate and effective decision-making. This effectively supports the development of the digital economy and innovative industries.

Future research could explore an integrated platform for smart infrastructure (an integrated management platform based on digital twins) to comprehensively manage, for example, carbon emissions, monitoring of the water environment, and waste treatment to facilitate the creation of smart industrial clusters and the provision of more efficient infrastructure and services. The key factors in building smart infrastructure include reliability and trust, information sharing and connectivity, use of AI technology in smart decision-making, and robustness in dealing with real-world problems. Cheng et al. [27] presented a vision of a smart infrastructure platform built to enable the digitization of work and the sharing of manpower [28].

3.3.2. Theories, contexts, methods

Theory is a means of academic progress. Like a compass, it provides scholars with a guide to support the achievement of their research goals [15]. In this review, approximately 20 traditional and innovative theories are discussed (Table 2). Theories in the framework construction category include SLR, PPP, smart city development, digital transformation, information sharing, energy efficiency, environmental and technological development, cybersecurity, smart green infrastructure, smart asset management, and sustainable development theories. The theories in the category of explaining and practicing include blockchain technology theory, information sharing theory, structural health monitoring theory, airborne IoT technology theory, and IoT technology theory. This proves that research on this topic has a solid theoretical foundation, and the existing theories can be fully utilized in future research, combined with the practical application of the situation to develop new theories, interdisciplinary innovation, and enrichment of the research theme.

From the perspective of the research background, smart infrastructure is driven by multiple factors: demand-driven factors, such as macro-demands, urbanization, sustainable development, and economic transformation, and technology-driven factors, such as the emergence of cutting-edge information technology, which creates opportunities and tools for intelligent infrastructure. Policy support: The United Nations Sustainable Development Agenda, strategic layout, and financial investment by governments provide strong support for research and applications. Only two of the research papers explored in this review fall into this category. Summarising the research methods used in this review (Table 2), approximately one-third of the studies used quantitative methods only. Fifteen studies used qualitative methods, with case studies (11 articles) being the most common.

Table 2(a). State-of-the-art overview of the ADO of smart infrastructure for advancing sustainable urban development and its TCM.

Antecedents			
Government-related	**Environmental-related**	**Technology-related**	**Social-related**
·Rapid urbanization [2, 4, 20, 23, 27, 29] ·Intelligent Transformational Development [25, 28] ·Insufficient public funding [1, 19, 29] ·Budgetary constraints [2, 19, 20] ·Smart City Development [19, 21, 22, 25, 30] ·Development of Intelligent Transportation Systems (ITS)[31] ·Resilience and sustainable development [1, 21, 32]	·Climate change and environmental stress [2, 20, 29] ·Resource constraints [19] ·Urban population growth [19, 20, 23, 33] ·Require low carbon emissions [34]	·Insufficient specialized knowledge [20, 29] ·Advances in digital technology(AI, DTs, IoT, cloud computing, UAVs, VR,5G,big data, block chain)[4, 22, 25, 27, 28, 30, 31, 33-35] ·Low-cost and efficient monitoring[36] ·IoT technology to improve monitoring and protection efficiency [37]	·Social and cultural needs [26, 35] ·Preservation and sustainability of urban heritage is essential)[37] ·Improvement of the quality of life of the population [1, 23, 24] ·Improvement of the quality of public services (water use, waste disposal) [23]) ·Network security, data security[33] ·Integration of urban functions[25]

Table 2(b). State-of-the-art overview of the ADO of smart infrastructure for advancing sustainable urban development and its TCM.

Decisions	Outcomes
·Explore the PPP model [1, 2, 19, 20, 29] ·Development of smart infrastructure platforms [28] ·Implementation of digitized smart infrastructure [4, 34, 37] ·Selection of comparisons to analyse parameter gaps[26] ·Design and implementation of smart infrastructure digital twins [32] ·Building an intelligent AI-based infrastructure [27] ·Exploring the application of IoT technology[24] ·Building UAVs for Dynamic Air Infrastructure in Smart Cities and Intelligent Transportation [31] ·Detecting Strain and Vibration in Infrastructure with SMS Multimode Fiber Optic Sensors [36] ·Smart technology combined with green infrastructure[23]	·Proposing a PPP modelling framework [19, 29] ·Intelligent Infrastructure Platform [28] ·Digitization of work and sharing of manpower have increased the efficiency of infrastructure work [28] ·New system developed for real-time data collection and analysis [37] ·Over-reliance on smart technologies can lead to wasteful use of resources and increased environmental burdens to maintain sustainability [26] ·PPP enablers and barriers identified [2] ·Real-time monitoring and management of railroad bridges using smart infrastructure digital twins [32] ·Proposing a DaaS framework [4] ·Validated key elements in building smart infrastructure [27] ·Validated the positive impact of IoT technology on smart city infrastructure [24] ·Verified that building smart infrastructure reduces carbon emissions [34] ·Validated the application of UAVs in dynamic aerial infrastructure for smart cities and intelligent transportation [31]

·Securing Smart Cities with CycleGAN Innovative Algorithms [33] ·Multidisciplinary integration [22, 35] ·Implementation of standardization for asset management [25] ·Introducing 3D Inspection Algorithms to Intelligent Infrastructure [30] ·Introducing Hybrid Strategies (HIHCS,AROS) to Optimize IoT Performance [21]	·Validated that multimode fibre optic sensors are more effective [36] ·Validated that smart green infrastructure provides better ecological outcomes [23] ·Validated that stakeholders are key to the success of PPP projects [20] ·Compare and contrast traditional PPP and smart PPP [1] ·Validated CycleGAN-based optimization algorithm to ensure smart city security [33] ·Suggests five key roles for civil engineers[35] ·Proposing a model for holistic asset management [25] ·Propose mechanisms and frameworks for the application of blockchain technology[22] ·Validation of the 3D inspection algorithm [30] ·Validation of HIHCS, AROS [21]

Table 2(c). State-of-the-art overview of the ADO of smart infrastructure for advancing sustainable urban development and its TCM.

Theories	Contexts	Methods
·PPP theory [1, 19, 20, 29] ·Theory of Smart City Development [1, 4, 19, 22, 24, 29, 31, 35] ·Digital twin theory[28] ·Aerial Internet of Things (IoD) Technology Theory [31] ·Theory of Intelligent Infrastructure Management [20, 27, 28, 32-34] ·Blockchain Technology Theory [22] ·Information sharing theory [28] ·Structural Health Monitoring (SHM) Theory [37] ·Theory of Intelligent Asset Management [25] ·Theory of Sustainable Development [1, 26, 34, 35] ·Building Life Cycle Assessment (LCA) Theory[26] ·Energy efficiency theory [26] ·Cyber-physical systems (CPS) theory [32] ·Machine Learning, Reinforcement Learning and Deep Learning Theory [27, 30, 31] ·Theory of environment and technology development [34] ·Theory of Computational Intelligence (CI) [21] ·Smart Green Infrastructure (SGI) theory [23] ·Whole Life Cycle Cost Management (WLC) Theory [25]	·Urbanization studies [29] ·Structural health monitoring is not met by high costs, etc.[36] ·Urban resource management, smart city management needs (logistics and distribution, environmental monitoring, traffic management, public safety) [21, 24, 30, 31] ·World's largest carbon emitter [14] ·Support for smart city development and disaster prevention, etc. [1, 4, 23, 28, 37] ·Too much smart technology has been introduced into the building sector, ignoring traditional strengths [26] ·Fewer workers [28] ·Digital twins continue to evolve [32] ·United Nations sustainable development goals [2] ·Requirements for collecting, transmitting, and analysing environmental data [27] ·Legacy infrastructures fail to meet digitization requirements [19, 20, 22, 28, 35]	·Systematic Literature Review [29, 35] ·Simulation experiment [33] ·Building a DTs Model of Infrastructure, Use of mobile mapping systems(MMS) [28] ·A Hybrid Approach to Combining IoT Technology with Structural Health Monitoring Technology[37] ·Case study [1, 4, 19, 22-27, 32, 35] ·Expert Interviews[2, 19, 23, 27, 35] ·Content analysis [2, 19] AHP [2, 32] ·Analysis of spatial benefit effects[34] ·Analysis of intermediation effects[34] ·Empirical analysis [20, 34] ·Experimental analysis [21, 30, 32] ·Model Training and Evaluation [30]

4. Conclusion

This systematic review aimed to address three main objectives. To this end, this study adopted a protocol based on SPAR-4-SLR and the ADO-TCM review frameworks. The background and antecedents of the emergence of research related to smart infrastructure, an indispensable component of sustainable urban development, are illustrated through a systematic analysis that promotes the development of related theories. The integrated ADO-TCM framework demonstrates that the use of the two frameworks allows for a more rigorous organization and formation of holistic insights into the themes of the review and that a systematic review based on the framework can contribute in a novel way to the literature. Second, for this review, based on the thematic content and the research context, it is demonstrated that government policies, digital technologies, and societal needs from the current development are driving the development of smart infrastructures, which can address key challenges such as resource constraints, environmental pressures, and population growth, and help improve urban resilience and promote sustainability. Third, Public-private partnership (PPP) models can ease financial burdens and enrich economic development. This study underscores the crucial impact of cutting-edge technologies, including artificial intelligence, the Internet of Things, and blockchain, on enhancing the effectiveness and security of urban infrastructure systems. The study also points out that smart infrastructure plays an important role in improving the resilience and sustainability of cities to climate change and natural disasters.

In addition, this study provides a comprehensive overview of theoretical, contextual, and methodological findings. The review indicates that there is neither a shortage nor an abundance of theories related to this subject. Based on these review insights, this study also proposes encouraging the advancement of theoretical novelty, enhancement of contextual relevance, and improvement of methodological rigor in future research based on real-world scenarios of application across disciplines. Future studies should focus on broadening the use of intelligent infrastructure for urban administration, investigating comprehensive systems based on digital twins, creating a uniform management framework, and improving the effective utilization of resources and system oversight.

5. Limitation

This study had several limitations. First, the data used for the literature review were limited to the Scopus and WoS databases, which may have missed relevant studies from other sources. Second, this study focused primarily on recent publications published between 2018 and 2024, which may have overlooked earlier foundational studies. Finally, this study relied primarily on bibliometric analysis, which, although useful, may not fully capture the complex interdisciplinary nature of smart infrastructure research. Therefore, further qualitative exploration is required in future studies.

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