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Sectoral Interconnectedness: insight from five sectors in 'smart' urban planning (Energy, Transport, Waste Management, Buildings, and Cities)

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Abstract

'Smart' urban planning has become integral to addressing contemporary urban challenges, with sectoral interconnectedness at the core of achieving sustainable, efficient, and resilient cities. This paper explores the level of interconnectedness across smart energy, Smart Transport, Smart Waste Management, Smart Buildings, and Smart Cities. This scope encompasses the complexities from site to city-wide scale. A mixed-method approach of qualitative thematic coding and quantitative correlation analysis, within NVivo's suit of cluster analysis, was employed. Strong interconnectedness was found between Energy and Transport, driven by digital transformation and data-driven decision-making. Weak interconnectedness was found between transformative cross-sectoral (CS) goals, e.g., climate adaptation and sustainability, and Waste Management and Building sectors, indicating that these critical components are not yet fully integrated into smart urban frameworks. Smart Cities were the most interconnected, acting as a central platform where CS goals like sustainability, digital transformation, and real-time data utilization are most connected to. While digital tools foster intersectoral connection, sectoral silos or inconsistent interoperability may hinder the realization of holistic smart urban outcomes. The results underscore the need for cohesive frameworks that methodologically align CS goals in the sectors, ensuring that technological innovations relate to long-term environmental and social goals. This paper offers actionable insights for policymakers and urban planners to enhance cross-sector collaboration, optimize urban systems, and achieve integrated, adaptive and sustainable smart urban planning.

Keywords: Smart urban planning, Sectoral interconnectedness, Smart energy, Smart transport, Smart waste management, Smart buildings, Smart cities

Introduction

Lack of integration/convergence among smart sectors

The term ‘smart’ has become a central concept in urban planning, reflecting a shift towards leveraging advanced technologies, data-driven strategies, and innovative practices to enhance urban efficiency, sustainability, and resilience (Anthopoulos, 2015; Russo, 2025). Its application spans various policy and planning sectors, leading to the emergence of ‘Smart Infrastructure’ (Broo *et al.*, 2022), ‘Smart Buildings’ (Borhani *et al.*, 2022), ‘Smart Traffic’ (Eldafrawi *et al.*, 2024), ‘Smart Transport’ (Haydari & Yilmaz, 2022), ‘Smart Mobility’ (Babapourdijojin *et al.*, 2024), ‘Smart Energy’ (Aliero *et al.*, 2022), and ‘Smart Urban Governance’ (Jiang, 2021). This multi-dimensional perspective integrates technology, people, and institutions, highlighting the role of Information Communication Technologies (ICTs) in shaping the future of cities and urban planning (Alrashed, 2020; Meng & Zhu, 2024). In this context, the interconnectedness of urban challenges, such as energy efficiency, carbon emissions reduction, and building sustainability, is recognized, implying that smart solutions should emphasize holistic approaches (Brčić *et al.*, 2018; Lee *et al.*, 2023). For example, Smart Energy solutions can influence the design and operation of Smart Buildings, while Smart Transport systems depend on city-wide infrastructure underpinned by Smart Governance.

Despite recognizing the concept of interconnectedness as crucial, the problem is that the extant literature predominantly addresses smart applications in isolated sectoral domains, e.g., Smart Transport, Smart Energy, and Smart Waste Management (Onyango *et al.*, 2025), with limited emphasis on their inherent synergistic potential. This sectoral isolation significantly hampers the realization of integrated and efficient urban sustainability, resilience, and innovation, likely diminishing the potential full impact of the concept ‘smart’.

Interconnectedness, as conceptualized here, involves explicitly analyzing, aligning, and strategically linking the smart elements, i.e., meanings, goals, and applications (see Onyango *et al.,* 2025), between two or more smart sectors. However, the lack of a systematic investigation into the interconnectedness required to facilitate integration among the various smart sectors may be a source of sub-optimality (e.g., ineffectiveness and inefficiency) within urban planning (Onyango *et al.*, 2025; Han & Kim, 2024). This is true, if 'smartness' (in policy and practice) is being pursued within sectoral silos bereft of a carefully considered and calibrated interconnectedness between the smart elements.

Onyango *et al.* (2025) explored whether the term smart was similarly understood and applied in three smart sectors (Energy, Transport, and Waste Management), and found that the meaning and eco-modernism goals pursued in each sector were not always the same; but steeped in the language of a technology-based paradigm which was hollow in meeting any fundamental transformation of the status quo. Furthermore, there were inadequate efforts regarding the coherent application of 'smart' in a manner aimed at achieving an overarching, converging, or collective goal across the sectors. Therefore, the concept of smart required a shared theoretical foundation applicable across the sectors.

Following the conclusion that smart planning was not always similarly understood and applied in the Energy, Transport, and Waste Management sectors, one wonders what the level of interconnectedness exists across the broader smart planning spectrum. This leads to the research question: To what extent do the various sectors of smart planning exhibit interconnectedness via their smart elements? Therefore, this paper aims to uncover how smart elements (i.e., meanings, goals, and applications) are interconnected across five sectors of urban planning. The insight can help policymakers and urban planners to better leverage smart elements towards achieving convergent outcomes within cohesive 'smart' urban planning (Kondiba & Kothalanka, 2023). This can contribute to answering Cavada *et al.* (2016), who asked whether planning could go beyond the pragmatic engineering-based attempt to improve the operation of individual urban infrastructure and/or services through technology, via an underpinning theory of the elements to be connected.

Following the introduction (section one), section two presents the idea of interconnectedness as part of setting out the context for analyzing and interpreting the findings. This is followed by the methodological approach outlining the procedures for data collection and analysis (section three). Subsequently, the results (section four) and discussions (section five) are presented. The study's conclusions and recommendations are drawn up in the final section (section six).

Interconnectedness: purpose, benefits, and challenges

Interconnectedness, as a theoretical framework in this paper, is premised on the acknowledgment that while each sector has its own bespoke application underpinning smart, there is also a need for some collective, aligned, or convergent big-picture outcome(s) to be delivered by smart. This follows from the concept of convergence (Onyango *et al.*, 2025), which suggests that the integration of sectoral elements within smart urban planning is necessary to achieve coherent and effective urban development. Although Smart Buildings and Smart Transport systems employ different technologies, ultimately, both aim to deliver the convergent goals of reducing carbon emissions and enhancing energy efficiency. Their effectiveness is significantly increased when they are strategically interconnected; within interdependencies that create a broader smart urban ecosystem where energy use, mobility patterns, digital governance, and carbon emission and/or sustainability objectives are coordinated and optimized, through holistic smart urban strategies (Esfandi *et al.*, 2024) and initiatives.

In terms of policy implementation (Hurlimann *et al.*, 2021), interconnectedness becomes crucial for creating a coherent framework that ensures the alignment of the conceptualization, calibration, and delivery of smart urban outcomes (Bruzzone *et al.*, 2021). This matters to the efficiency and effectiveness of urban planning based on a growing awareness that leveraging the synergies among elements (i.e., meanings, goals, and applications) of various smart sectors can be a cost-effective way to address the interrelated nature of urban challenges (Javed *et al.*, 2022, Onyango *et al.*, 2025) as resources are limited.

Interconnectedness can be exemplified within the lens of Sustainable Smart Planning Theory and Cyber-Physical Systems, emphasizing integrated, holistic approaches necessary for transformative smart urban outcomes. Thus, highlighting the seamless integration of physical infrastructure with digital technologies (Andronie *et al.*, 2021), ensuring that technological advancements align with long-term environmental, social, and economic goals (Bruzzone *et al.*, 2021).

Despite the recognition of interconnectedness, sectoral fragmentation continues to hinder cities from fully harnessing the potential of smart urbanism (Cai *et al.*, 2023): as coordinated interconnectedness is often not evidenced. Other studies have identified challenges to interconnectedness, for instance, technological fragmentation hindering the convergence of outcomes as sector-specific tools are often developed in silos without consideration for interoperability (Balica & Cuțitoi, 2022), thus limiting opportunities for cross-sectoral synergies. Data fragmentation compounds these challenges (Javed *et al.*, 2022). Each sector generates large volumes of data, yet inconsistencies in data formats, privacy concerns, and a lack of interoperable systems can prevent effective data sharing and analysis (Braun *et al.*, 2018). Regulatory and institutional barriers (Venegas *et al.*, 2021) can further exacerbate these challenges, as sector-specific policies frequently operate independently, creating silos that impede the development of cohesive approaches to urban planning.

One way to address the above challenges requires a linkage of rationale and calibration in terms of smart elements (understanding, goals, applications) across sectors, to better coordinate and integrate the concept and practice of smart. For example, the alignment of Smart Energy elements with those of Smart Transport could simultaneously reduce emissions and enhance mobility. Furthermore, Smart Buildings can act as critical nodes within a city's energy network, contributing real-time data on energy use and environmental conditions that inform and underpin urban planning strategies. Smart Waste Management elements can also be integrated into broader Urban Governance elements, supporting decentralized waste processing and promoting the overarching goal of a circular economy.

In practice, realizing interconnectedness will require awareness of the smart elements and their inherent potentialities, when interconnected, among the sectors. The vision is for urban planners and policymakers to be able to build interconnected ‘smart’ ecosystems that maximize the potential of each smart sector while aligning and integrating sectoral interdependencies, for example, at the elements level (i.e., meanings, goals, and applications).

Methodological Approach

Following a content analysis approach, this paper will employ qualitative analysis via thematic coding and quantitative analysis via correlation analysis within NVivo’s cluster analysis function. Data collection to analyze the level of interconnectedness was as described in Onyango *et al.* (2025), but with two differences. One, the three smart sectors (Energy, Transport, and Waste Management), was expanded by adding Smart Buildings and Smart Cities. Two, the city scale added a broader overarching platform upon which the other sectors and their smart elements interact within a dynamic arena that shapes both the smart opportunities and barriers towards smart outcomes (Han & Kim, 2024). A summary of the methodological steps is described below.

Step 1. A systematic review of literature supported by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to guide the identification of documents was undertaken. Search criteria encompassing keywords such as “smart energy,” “smart transport,” “smart waste management,” “smart buildings,” and “smart cities” were applied. Boolean operations (e.g., "smart AND energy OR transport OR buildings OR cities") were applied in Google Scholar, Scopus, and

ScienceDirect to retrieve relevant academic articles, book chapters, and conference proceedings. The initial search yielded over 150,000 documents. A staged review process was implemented to refine the dataset, consisting of reviewing titles, abstracts, and full texts. Inclusion and exclusion criteria were applied, resulting in the selection of 201 documents that formed the basis for subsequent analysis (Figure 1).

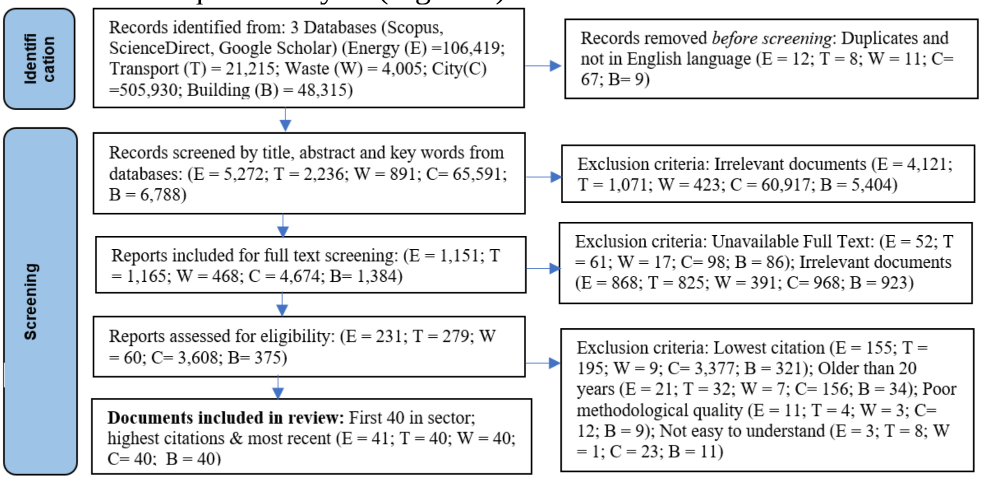

Figure 1. PRISMA ensures that the search for relevant literature to analyze is systematic and transparent (adapted from Page *et al.*, 2020)

Step 2. Each document from Figure 1 was coded line-by-line to ensure consistency and rigor. Data extraction was conducted using NVivo software to facilitate textual analysis based on codes developed to categorize data into three main elements of the term smart (Onyango et al., 2025):

- **Understandings**: Texts describing how smart is defined or understood within each sector (Code M).
- **Goals**: Statements outlining the overarching aims or priorities of smart implementations (Code G).
- **Applications**: Descriptions of specific technologies or processes used to operationalize smart concepts (Code D).

Step 3. The codes (M, G and D) were analyzed using various NVivo (V1.5) cluster analysis functions. First, the word cloud function was applied to M codes to explore key patterns in the texts used. Second, interconnectedness across the sectoral goals and applications (G and D codes) was generated using the Hierarchical Chart option to illustrate the relative prominence of each cross-sectoral (CS) goal, showing the proportional distribution and interconnectedness in the data set. Third, the Coding Comparison Query function was applied to CS goals to show the sectoral distribution (intensity) by goals. Fourth, Circle graphs, based on Pearson correlation coefficient

analysis, helped to show how lines of ‘connectivity’ from one sector were connected to another sector by frequency. Finally, cluster analysis of divergence patterns was generated using a horizontal dendrogram.
Overall, these analyses emphasized the linkages and facilitated an understanding of how smart elements of these sectors are interconnected. The strength of interconnectedness was determined using NVivo’s correlation and cluster analysis tools, where higher coding co-occurrence via higher Pearson correlation coefficients indicates "strong" connections. Moderate and Weak connections, respectively, were determined by progressively lower correlation values and fewer shared codes across sectors and goals (Table 1).

Table 1. A summary of the strengths of interconnectedness between CS elements based on correlation coefficient data within NVivo software. See results in Figures 4 – 9.

Connection Strength	Measurement criteria (NVivo Analysis) and our interpretation
Strong	High level of interconnection between two sectors (Red line)
Moderate	Medium degree of interconnection (Green line)
Weak	Limited or minimal interconnection, sectors function mostly in isolation with little thematic overlap (Black line)

Some limitations with our document analyses are worth mentioning (Bowen, 2009). For example, documents may not be complete or written in an objective fashion; it might be difficult to determine which information is precise or unbiased, and; documents may have insufficient detail as they are produced for some purpose other than research. A document may also state something very different from all the other documents. Overall, we aimed to mitigate bias and uncertainty by using the same coding where the reference was to the same element of interest. Furthermore, the PRISMA approach helped us systematically identify the relevant documents to analyze. However, repeatability of the work can be restricted as documentation retrievability by another researcher may not reveal a set of documents identical to ours.

Results

Interconnectivity: Convergence in goals and applications

The analysis of the 75 most frequent words (Figure 2) across goals and applications codes (i.e., G and D) reveals significant patterns of convergence in how smart is conceptualized across the five sectors. The centrality of terms such as ‘data’, ‘systems’, and ‘energy’, followed by ‘information, planning, management, transportation, renewables and traffic’, highlights their foundational roles in defining smart urban systems. ‘Energy’ emerges as a core component, not only as a standalone sector but also as a supporting element for other sectors like Transport and Buildings, underscoring the vital function of energy in enabling integration and operational efficiency across smart systems.

Figure 2. The 75 most frequent words among the sectors focusing on goals and application

Word	Count
Energy	29693 (27.9%)
Smart	19930 (18.7%)
Buildings, cities	9589 (9.0%)
System, planning	8362 (7.9%)
Information	5380 (5.1%)
Traffic	5295 (5.0%)
Management, optimal	5291 (5.0%)
Renewable	4598 (4.3%)
Model	4509 (4.2%)
Data	4476 (4.2%)
Demand	4347 (4.1%)
Transportation	4336 (4.1%)
Cost	4054 (3.8%)
Sustainability, environment	2764 (2.6%)
Technologies	2748 (2.6%)
Efficiency	1960 (1.8%)
Integration	1838 (1.7%)
Total	119170(100%)

Terms like ‘buildings’ ‘traffic’ and ‘cities’ emphasize the importance of infrastructure within smart systems. Buildings play a dual role as significant energy consumers and contributors to broader urban goals. They act as nodes in urban networks, linking energy management, transport, and data-sharing systems.

Technology and data are prominent themes, as evidenced by the frequent mention of terms such as ‘model’, ‘systems’, ‘information’, and ‘technology’. This convergence highlights the reliance on advanced tools like the Internet of Things (IoT), and real-time analytics to drive optimization in the sectors. These technologies underpin the ability to achieve energy efficiency, improve traffic flow, and reduce waste. The repeated focus on these tools suggests a shared understanding that technological innovation is central to achieving the objectives of smart urban systems.

The word frequency analysis (Table in Figure 2) reveals a *relatively* strong emphasis on sustainability (2.6%) and ‘renewable’ (4.3%). The term ‘integration’ (1.7%) points to a collective effort to interconnect systems and align sector-specific operations with broader urban planning goals. Words such as ‘cost’, ‘demand’, ‘optimal’, and ‘time’, reflect the financial and logistical barriers to implementing smart systems, thus implying the need for collaborative CS approaches that leverage technology to overcome these barriers.

Overall, while the sectors may have distinct objectives, the frequent recurrence of certain terms suggests that the sectors share a common understanding of smartness: providing a sense of interconnectedness as a foundation for coordinated action and interoperability in urban planning.

Areas where convergence is observed are areas where cohesive frameworks to enhance optimized and seamless integration across interconnected domains can occur.

Interconnectedness: goals and applications

Analyzing the coded data by sector revealed that certain priority themes consistently emerged across them. These recurring themes, with some overlaps, were distilled into five cross-sectoral (CS) goals (Figure 3) and sub-goals in parentheses:

CS1: **Sustainability** (Renewable energy, Environmental conservation, Social equity, Greenhouse gas emissions, Sustainable resource consumption).
CS2: **Resource Optimization** (Energy efficiency, Reduce waste generation and promote recycling, Optimize transport networks for minimal environmental impact, Water-saving technologies, Circular economy practices).
CS3: **Real-Time Data Utilization** (Predictive analytics for urban planning, IoT for dynamic system monitoring, Integrate real-time traffic, Real-time decision-making, Data-sharing platforms).
CS4: **Climate Adaptation** (Infrastructure resilience, Flood and disaster preparedness, Heat-resilient urban designs, Adaptive governance frameworks, Climate risk assessment).
CS5: **Digital Transformation** (Smart city technologies (IoT, AI, Big Data), Integrated city dashboards for monitoring, Digital governance and citizen engagement, Platforms for cross-sector data integration, Cybersecurity in urban digital systems).

In Figure 3, the size of the rectangle illustrates the relative prominence of each goal, showing its proportional distribution within the dataset. This is based on NVivo's coding density and co-occurrence analysis, i.e., overall presence and strength of connections rather than absolute frequency counts. Digital Transformation (CS5), followed by Climate Adaptation (CS4), are the most frequently stated goals, while Resource Optimization (CS2) and Sustainability (CS1) appear less frequently. We note the prominence of what can be described as 'operational goals' (i.e. CS2, CS3, CS4, CS5), referring to strategies and actions that enable processes, e.g., Digital Transformation, facilitating automation and connectivity. In contrast, outcome or transformative goals representing overarching targets i.e. CS1 and CS4, are less prominent.

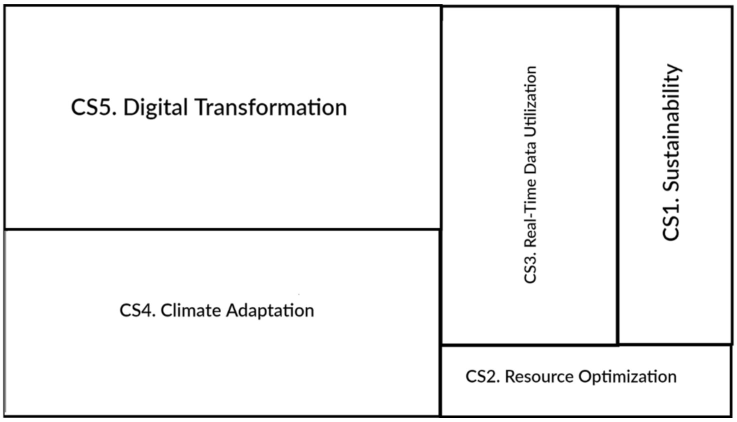

Figure 3. Cross-sectoral goals among the five sectors generated using the Hierarchical Chart option in NVivo

To further analyse interconnectedness, the percentage contribution of the five CS goals, by sector (sectoral intensity by goal) was generated using NVivo's Coding Comparison Query function. The values were derived by comparing coding references across different sectors and goals, i.e., specifying CS goals (CS1 to CS5) as nodes and defining sources (codes G and D) (Table 2).

Table 2. How do different sectors contribute to the cross-sectoral goals? The two highest percentage contributing sectors for each goal are in red

Smart sectors	CS1	CS2	CS3	CS4	CS5	**Total**	**Average**
Cities	**35**	20	**25**	**30**	**35**	145	29
Energy	**25**	**30**	20	15	20	110	22
Waste Management	15	**25**	10	10	5	65	13
Building	15	15	15	**25**	15	85	17
Transport	10	10	**30**	20	**25**	95	19

As expected, Smart Cities was the most interconnected sector, as a hub where environmental, economic, and social sustainability efforts converge. Energy and Transport were the next most interconnected sectors, while Waste Management was the least interconnected to other sectors. In terms of CS goal intensity, Smart Cities lead, followed by Smart Energy, Smart Transport, Smart Buildings, and lastly, Smart Waste Management.

Various sectors present opportunities for different levels of CS goals. Smart Energy leads in Sustainability (CS1) and Resource optimization (CS2) goals, while Smart Transport leads in Real-time data utilization (CS3) and Digital transformation (CS5) goals. Smart Waste Management is disproportionately focused on Resource optimization (CS2) relative to all other goals.

Smart Energy remains highly dependent on Resource Optimization (CS2), ensuring that resources are used in a way that supports long-term sustainability. In contrast, Smart Transport and Smart Buildings are more dependent on Real-Time Data Utilization (CS3) and Digital transformation (CS5) and Climate adaptation (CS4), respectively. Overall, CS goals appear more prominent and perhaps better developed within Smart Cities, Energy and Transport sectors, while less prominent and less developed in Smart Waste Management and Smart Buildings. Table 2 also reveals that the Sustainability goal (CS1) is least developed in the Smart Transport, Buildings, and Waste Management sectors, while the Climate adaptation goal (CS4) is least developed in the Waste Management and Energy sectors.

On average (Table 3), the number of strong connections (1.6 per goal) is 33% higher than weak connections (1.2 per goal) across all CS goals. Both moderate and weak connections together (2.0 per goal) exceed strong connections (1.6 per goal) by 25%. Of notable concern, 50% of the weak connections are associated with Climate Adaptation (CS4), suggesting that climate resilience planning is not yet fully integrated into smart urban strategies. Additionally, digital transformation (CS5) and Real Time data utilization (CS3), which underpin the technological dimensions, are yet to be imbued with climate adaptation goals. This implies significant room for enhanced interconnectedness among the sectors.

Table 3. Proportional distribution of the levels of interconnections among CS goals (CS1 – CS5)

CS goal	Strong	Moderate	Weak	Total
CS1	3	0	0	3
CS2	2	1	1	4
CS3	1	1	1	3
CS4	1	0	**3**	4
CS5	1	2	1	4
Total	8	4	6	18
Average	**1.6**	**0.8**	**1.2**	Av. 3.6

Figure 4 reveals how a CS goal like Sustainability (CS1) plays a crucial role as it is directly connected to 3 other goals (CS2, CS4, CS5); while Climate adaptation (CS4), is weakly connected to most other goals except to Sustainability, where there is a strong connection in the documents analyzed. Sustainability (CS1) is the most interconnected goal, emphasizing its role in uniting various CS goals. Its strong connections to Resource Optimization (CS2), Digital Transformation (CS5), and Climate Adaptation (CS4) indicate that sustainability is embedded within operational efficiency, technological advancements, and resilience planning. Thus, Sustainability does not function as an isolated objective but instead depends on integrated processes that optimize resources, leverage digital tools, and incorporate data-driven strategies to support informed decision-making. These strong ties confirm that achieving Sustainability requires a system-wide approach that aligns technological progress with environmental objectives to ensure long-term urban resilience and efficiency.

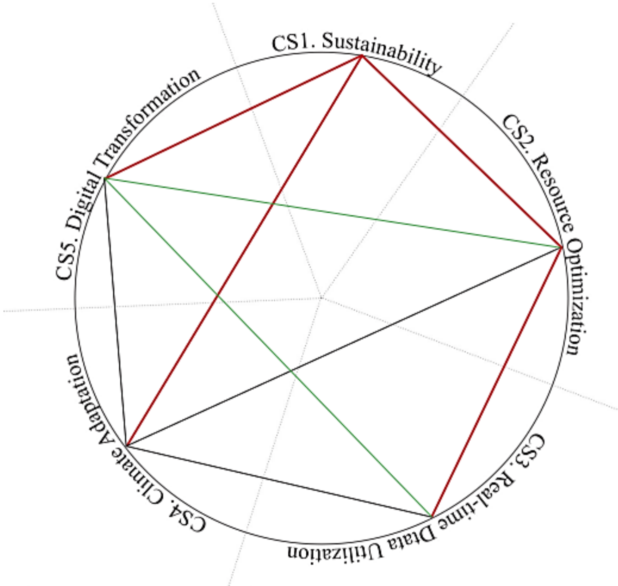

Figure 4. Interconnections among CS goals and applications. A red line denotes a strong connection, a green line denotes a moderate connection, and a black line denotes a weak connection

Conversely, Climate Adaptation (CS4) remains the least integrated goal, exhibiting weak connections to most other goals and having only one strong link to Sustainability (CS1). This asymmetry exposes a significant gap where Resilience Strategies (CS4) are recognized but remain underutilized and insufficiently embedded within the broader framework of CS goals. The weaker ties indicate that while Climate Adaptation lacks the same level of operational, technological, and data-driven integration, which supports Sustainability, Resource Efficiency, and Digital Transformation. Thus, functions as an isolated rather than an integrated component of smart urban strategies.

Figure 4 also reveals a strong operational core centered around Resource Optimization (CS2), Real-Time Data Utilization (CS3), and Digital Transformation (CS5), which collectively drive efficiency, technological integration, and sustainability. The strong connections between these three goals underscore the role of optimization and data-driven approaches in improving urban efficiency. However, the weak connection involving Climate Adaptation (CS4) indicates that resilience planning has not yet been fully incorporated into these operational and technological strategies, leaving a critical gap in the network of CS goals.

To strengthen the interconnections within the network, greater emphasis should be placed on reinforcing Climate Adaptation (CS4) as a core element of sustainable urban planning. This requires linking climate adaptation strategies to sustainability goals and embedding them into data-driven decision-making and resource management frameworks to enhance adaptability and long-term urban resilience.

Additionally, deepening the moderate ties between Digital Transformation (CS5) and Resource Optimization (CS2) could lead to new synergies, allowing digital innovations to drive resource efficiency more effectively. Similarly, enhancing the connection between Real-Time Data Utilization (CS3) and Climate Adaptation (CS4) could facilitate more dynamic and responsive resilience planning, ensuring that real-time analytics inform climate-responsive strategies and adaptive infrastructure development. This shows a need for transitioning from a more data-driven model to a more balanced approach that integrates operational efficiency, sustainability, and adaptive resilience: strengthening these interconnections is essential to ensuring that smart urban planning is optimized for technological and resource efficiencies and capable of withstanding long-term climate and environmental challenges. Subsequently, the detailed results from examining the distribution of interconnections for each CS goal and its sub-goals are presented.

Interconnectedness of sub-goals within Sustainability goal (CS1)

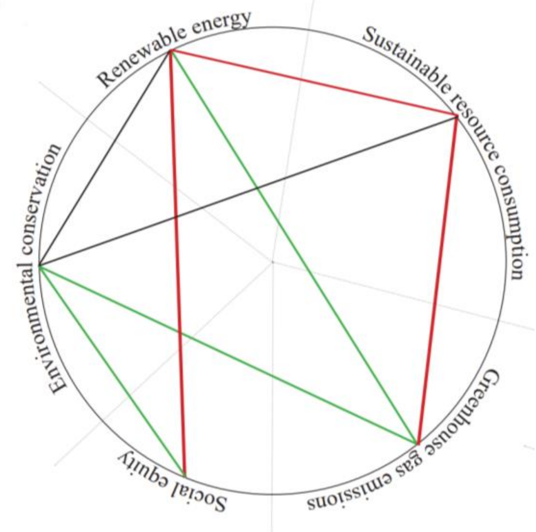

Figure 5. Interconnection of the sub-goals within the Sustainability goal (CS1) among the five sectors based on Pearson correlation coefficients generated from NVivo cluster analysis function

Within the Sustainability goal (CS1), Renewable energy was strongly connected to Social equity and Sustainable resource consumption, as are Sustainable resource consumption and Greenhouse gas emissions (Figure 5). However, Environmental conservation is weakly connected to Renewable energy and Sustainable resource consumption. Furthermore, Social equity did not have even a weak connection to Sustainable resource consumption or Greenhouse gas emissions. Thus, sustainability efforts lack strong integration with social justice and biodiversity conservation measures and emerge as clear areas for strengthening the interconnections.

Interconnectedness of sub-goals within Resource Optimization goal (CS2)

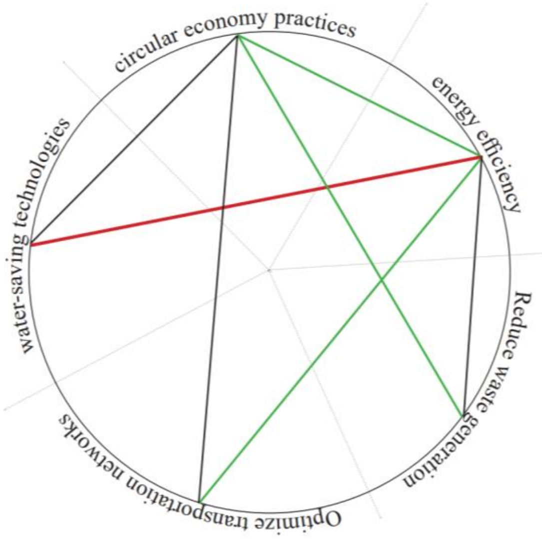

Figure 6. Interconnection of the sub-goals within the Resource Optimization goal (CS2)

Figure 6 underscores the fragmentation of resource optimization efforts, where Energy and Water efficiency exhibit strong interconnectedness, reflecting the recognition that water and energy systems are interdependent in urban sustainability planning. Moderate connections were observed between the Circular economy and waste generation and Energy efficiency, and also between Energy efficiency and Transport networks. Circular economy was weakly connected to Water and Transport, and Energy efficiency was weakly connected to Waste generation, suggesting that the strategies are not yet fully aligned.

Interconnectedness of sub-goals within Real Time data Utilization (CS3)

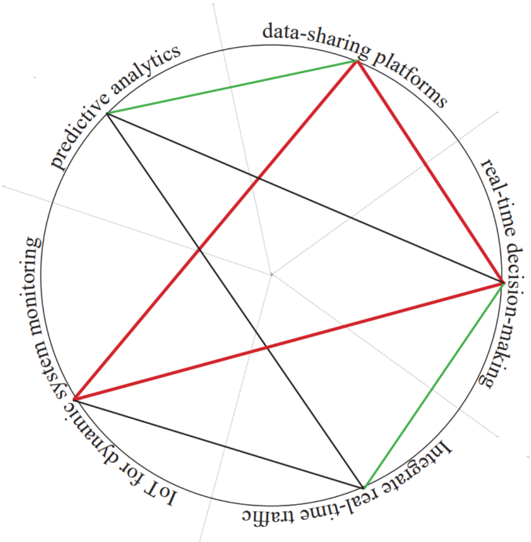

Figure 7. Interconnection of the sub-goals within Real-time data utilization (CS3)

In Figure 7, the strongest connections are between Data-sharing platforms, Real-time decision-making, and IoT for dynamic system monitoring, indicating that data utilization is most effectively leveraged when real-time data flows across platforms and supports automated decision-making in urban systems. However, weaker connections to Predictive analytics and Integrated real-time traffic suggest that while real-time data supports immediate decision-making, based on operational responses rather than future scenario modeling, its long-term forecasting and transport integration capabilities are less developed. This type of weak connection to Integrated real-time traffic implies that data-driven mobility management still lacks full integration into broader urban data-sharing and decision-making frameworks.

Interconnectedness of sub-goals within Climate Adaptation (CS4)

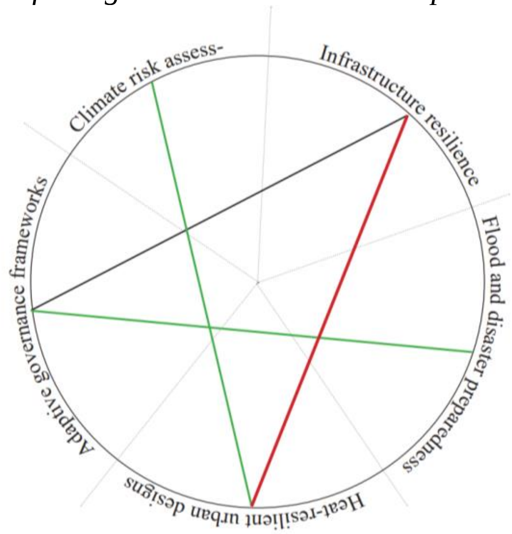

Figure 8. Interconnection of the sub-goals within the Climate Adaptation goal (CS4)

While the Climate Adaptation goal (CS4) connects to all other goals in the circle graph (see Figure 4), the strength of connections among its sub-goals varies. The strong connection is between Infrastructure resilience and Heat-resilient urban designs, emphasizing the critical role of built environment adaptations in mitigating climate-related challenges. This strong tie suggests that urban resilience strategies heavily rely on heat-resistant infrastructure, e.g. green building standards, and adaptive urban planning to counteract extreme heat events and other environmental stressors. However, the moderate connections between Climate risk assessment and Heat-resistant urban designs, and between Adaptive governance frameworks and Flood and disaster preparedness, indicate gaps in integrating proactive risk management, policy frameworks, and disaster response mechanisms within climate adaptation strategies. The lack of stronger connections in these areas suggests that while physical infrastructure is being reinforced, climate adaptation's broader governance and predictive risk assessment aspects remain underdeveloped.

Interconnectedness of sub-goals within Digital Transformation goal (CS5)

There is a strong link between Technologies, Integrated city dashboards and Digital governance, and Citizen engagement (Figure 9). While reflecting the increasing reliance on smart platforms for urban management and data-driven decision-making, the strong tie to Citizen engagement suggests that digital transformation plays a role in enhancing public participation and digital inclusivity in governance frameworks.

Moderate connections are between Cybersecurity and Citizen engagement and also between Integrated city dashboards and Digital governance and Digital governance.

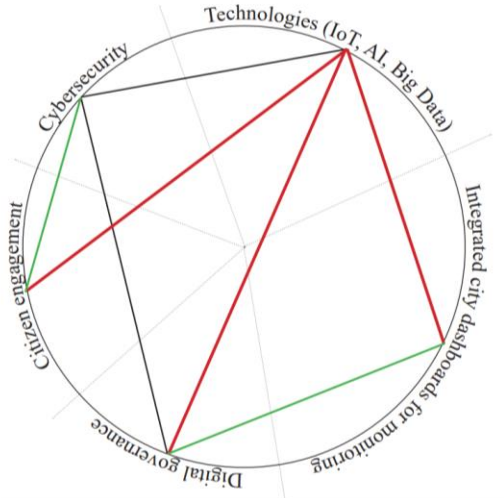

Figure 9. Interconnection of the sub-goals within Digital Transformation (CS5)

However, there is a weak connection between Cybersecurity and Digital governance and IOT, indicating a lack of robust integration with security measures and administrative cohesion. Furthermore, while digital and technological solutions are prominent, they were isolated without deep interconnections to broader sustainability sub-goals. This indicates that digital transformation primarily focuses on governance and monitoring rather than being strategically embedded into sustainability-driven or climate-resilient urban strategies (Figure 9).

Interconnectivity from a Dendrogram

Patterns of divergence also act as markers of interconnectedness. The cluster analysis (Figure 10) reveals varying distances between goals, indicating the degree of alignment or interconnectedness in their focus and application. Goals that appear farther apart, e.g., Digital Transformation (CS5) and Real-time Data Utilization (CS3), on the one end, and Sustainability (CS1) on the opposite end, implying least interconnectivity between the two sets of goals.

Figure10. Cluster analysis showing convergence/divergence patterns among CS goals and applications

Interestingly, Sustainability (CS1), being farthest from the digital technology aspects (CS3 and 5), reveals that the application of technology was often not integrated with the sustainability agenda. Figure 10 also visualizes the worrisome distance between Resource Optimization (CS2) and Digital Transformation (CS5) goals. Clearly, exploring how to achieve deeper alignment and integration between these sets of goals remains an avenue for improved application of smart urban planning. Addressing these relatively low levels of interconnectedness will require a deliberate effort to integrate and calibrate these goals, ensuring that technological advancements, environmental sustainability, and social equity are aligned rather than at odds. Or put another way, analyzed synergistically rather than traded off against each other.

Discussion

Most of the interconnected CS goals (CS2, CS3, CS4 and CS5) are essentially operational in nature. Outcome goals (CS1 and CS4), which can also be driven by the operational goals (Cai *et al.*, 2023), are relatively fewer in the network of goals. Notably, most CS goals and applications emphasize efficiency, digital transformation, and data-driven decision-making. It was also clear that digital solutions play a key role in enabling interconnectedness, although some applications were more interconnected with certain goals and not others. Goals exhibiting strong interconnectedness, such as those related to real-time data utilization and optimization, are learning grounds for an enhanced theoretically driven integration of goals, applications, and technologies in smart urban planning.

The findings also reveal important divergences in goals and applications, challenging the idea of seamless interconnectivity. The gap between resource optimization and climate adaptation highlights this divergence, as resource efficiency is often driven by short-term cost-saving measures, whereas climate adaptation and resilience planning require long-term investment in adaptive strategies. This weak interconnection suggests that optimization and efficiency-driven approaches are not yet fully interconnected to/with transformative goals, e.g., sustainability or resilience.

This reveals significant opportunities for exploring how to further connect different CS goals, especially those which are transformational (see Gjorgievski *et al.,* 2022), rather than reinforcing existing sectoral silos.

The key message is that while sustainability and digital transformation are essential pillars of smart urban planning, their interconnectivity remains underdeveloped, suggesting that technological advancements are not always leveraged in ways that directly support long-term sustainability and climate goals. Our results agree with Gazzola *et al.* (2019), who found that sustainability was not always a goal that is carefully considered and strongly connected with the digital technologies within smart approaches. Addressing these inadequate connections will require a shift towards optimization frameworks and digital transformations that are underpinned by sustainability objectives rather than solely focusing on technology-led efficiency and governance.

While technologies offer a framework for sectoral interconnectedness, their effectiveness is likely constrained by limited interoperability across different applications across sectors. Smart Cities can function as effective platforms for sectoral interconnectedness, aggregating and analyzing data from multiple sectors, yet individual applications often deploy these technologies in narrowly focused and isolated ways. This lack of system-wide interconnectivity will limit the full potential of CS technological integration, reinforcing the need for 1) standardized protocols and collaborative digital frameworks that enable seamless data exchange and coordinated governance, and, 2) deeper theorization of how to bring about effective synergies across sectors.

This study contributes to the discourse on smart urban planning by highlighting the levels of, and the potential barriers and opportunities for, deeper interconnectedness within the formulation and application of smart urban planning sectors. This seminal empirical insight is more generalizable and is valuable for practitioners and policymakers aiming to leverage smart elements to achieve efficient and cost-effective smart outcomes. Essentially, it helps address the risk that efficiency-driven and optimization-focused approaches are not well interconnected to broader sustainability objectives.

While Onyango *et al.* (2025) explored levels of convergence in three smart sectors (Energy, Transport, Waste Management), this paper goes further to provide deeper insight into the key areas of strong, moderate and weak interconnectedness of the elements of smart (i.e., understandings, goals, applications). It does this across five sectors, which are very different in spatial nature and scales, thus providing insight that is underlaid with more nuance and complexity, inherent in practice.

This distinction in spatial scales underscores the different spatial characteristics of smart sectors, where Buildings and Waste Management operate at localized scales, while Smart Cities function at a macro level (Han & Kim, 2024), integrating multiple sectors and extending across wider urban territories. This requires coordinated interconnectedness across various levels and dimensions of urban planning. The findings of this study can further support the application of Cyber-Physical Systems (CPS) and Sustainable Smart Planning theories (Pacheco & Hariri, 2016), by enhancing our understanding of the profile of interconnectedness across at least five smart urban sectors. This can facilitate more targeted applications in digital transformation and real-time data utilization, and the integration of technological innovation with long-term sustainability and governance frameworks (Machado *et al.*, 2023; De Jong *et al.*, 2015). Taking the term smart to include elements of meanings, goals and applications, has been a methodological strength as it allows analysis to be based upon a comprehensive perspective of the term.

However, a key limitation of this paper is its lack of a narrower area of focus, e.g., regional-scale analysis to show how sectoral interconnectedness differ, especially regarding variations in smart planning approaches, policy, and economic conditions. Future research looking at multi-regional comparative studies could provide deeper insights into how geographical and policy-specific factors influence sectoral integration, offering a more nuanced understanding of smart urban planning dynamics.

Conclusion and recommendations

The term smart has become a central concept in urban planning, reflecting a shift towards leveraging advanced technologies, data-driven strategies, and innovative practices to enhance urban efficiency, sustainability, and resilience. In this multi-dimensional perspective, the interconnectedness of urban challenges, such as energy efficiency, carbon emissions reduction, and housing sustainability is well recognized; implying that smart solutions should emphasize holistic approaches. However, despite recognizing the concept of interconnectedness as crucial, the problem is that the extant literature predominantly addresses smart applications in isolated sectoral domains, e.g., Transport, Energy, and Waste Management, with limited emphasis on their inherent synergistic potential. This sectoral isolation can significantly hamper the realization of integrated and efficient urban sustainability.

This paper set out to explore the level of interconnectedness, viewed as the linking of smart elements, i.e., meanings, goals, and applications, between five smart sectors (Energy, Transport, Waste Management, Buildings and Cities). This was based on document analysis, informed by thematic analysis using codes of smart elements from documents identified by the PRISMA approach. The findings reveal that sectors like Smart Energy and Smart Transport demonstrated strong interconnectedness of smart elements, particularly in digital transformation, real-time data utilization, and resource optimization. However, Smart Waste Management and Smart Buildings exhibited weaker interconnectedness, particularly concerning sustainability and climate adaptation, highlighting gaps in the cohesive application of transformative strategies.

If optimizing smart elements for efficiency and cost-effectiveness is a central goal in urban planning, this paper provides seminal insight for considering areas for intervention to increase the interconnectedness of smart elements. A well-conceived approach to coordinating the interconnectedness, sector-to-sector level or site-to-region or city scale levels of smart applications, has the advantage of a systems-wide approach to optimize urban functions. Where technological innovation, environmental stewardship, and social governance are not treated as separate domains but as interconnected components of a cohesive whole.

This paper's findings underscore the urgent need for frameworks that facilitate this level of integration via interconnectedness, thus ensuring that the potential of smart urban planning is fully realized in ways that are sustainable, adaptive, and inclusive. As this study was based on only five sectors, there is scope for more sectors to be included in similar studies, across various jurisdictions, to explore not only the generalisability of the phenomenon of interconnectedness but also how to enhance it.

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References:

1. Aliero, M. S., Asif, M., Ghani, I., Pasha, M. F., & Jeong, S. R. (2022). Systematic Review Analysis on Smart Building: Challenges and Opportunities. In *Sustainability (Switzerland)* (Vol. 14, Issue 5). MDPI. https://doi.org/10.3390/su14053009
2. Almalki, F. A., Alsamhi, S. H., Sahal, R., Hassan, J., Hawbani, A., Rajput, N. S., Saif, A., Morgan, J., & Breslin, J. (2021). Green IoT for Eco-Friendly and Sustainable Smart Cities: Future Directions and Opportunities. *Mobile Networks and Applications 2021 28:1*, *28*(1), 178–202. https://doi.org/10.1007/S11036-021-01790-W

3. Alrashed, S. (2020). Key performance indicators for Smart Campus and Microgrid. *Sustainable Cities and Society*, *60*, 102264. https://doi.org/10.1016/J.SCS.2020.102264
4. Andronie, M., Lăzăroiu, G., Ștefănescu, R., Uță, C., & Dijmărescu, I. (2021). Sustainable, Smart, and Sensing Technologies for Cyber-Physical Manufacturing Systems: A Systematic Literature Review. *Sustainability 2021, Vol. 13, Page 5495*, *13*(10), 5495. https://doi.org/10.3390/SU13105495
5. Anthopoulos, L. G. (2015). Understanding the Smart City Domain: A Literature Review. *Public Administration and Information Technology*, *8*, 9–21. https://doi.org/10.1007/978-3-319-03167-5_2/TABLES/4
6. Babapourdijojin, M., Corazza, M. V., & Gentile, G. (2024). Systematic Analysis of Commuting Behavior in Italy Using K-Means Clustering and Spatial Analysis: Towards Inclusive and Sustainable Urban Transport Solutions. *Future Transportation 2024, Vol. 4, Pages 1430-1456*, *4*(4), 1430–1456. https://doi.org/10.3390/FUTURETRANSP4040069
7. Balica, R. Ștefania, & Cuțitoi, A. C. (2022). Ethical Artificial Intelligence in Smart Mobility Technologies: Autonomous Driving Algorithms, Geospatial Data Mining Tools, and Ambient Sound Recognition Software. *Contemporary Readings in Law and Social Justice*, *14*(2), 64–81. https://doi.org/10.22381/CRLSJ14220224
8. Borhani, A., Borhani, A., Dossick, C. S., & Jupp, J. (2022). Smart Building Conceptualization: A Comparative Analysis of Literature and Standards. *Construction Research Congress 2022: Infrastructure Sustainability and Resilience - Selected Papers from Construction Research Congress 2022*, *1-A*, 310–318. https://doi.org/10.1061/9780784483954.032
9. Braun, T., Fung, B. C. M., Iqbal, F., & Shah, B. (2018). Security and privacy challenges in smart cities. *Sustainable Cities and Society*, *39*, 499–507. https://doi.org/10.1016/J.SCS.2018.02.039
10. Brčić, D., Slavulj, M., Šojat, D., & Jurak, J. (2018). The Role of Smart Mobility in Smart Cities. *Road and Rail Infrastructure V*, *5*, 1601–1606. https://doi.org/10.5592/co/cetra.2018.812
11. Bruzzone, M., Dameri, R. P., & Demartini, P. (2021). Resilience Reporting for Sustainable Development in Cities. *Sustainability 2021, Vol. 13, Page 7824*, *13*(14), 7824. https://doi.org/10.3390/SU13147824
12. Cai, M., Kassens-Noor, E., Zhao, Z., & Colbry, D. (2023). Are smart cities more sustainable? An exploratory study of 103 U.S. cities.

Journal of Cleaner Production, *416*, 137986. https://doi.org/10.1016/J.JCLEPRO.2023.137986
13. Cavada, M., Hunt, D. V. L., & Rogers, C. D. F. (2016). Do smart cities realise their potential for lower carbon dioxide emissions? *Proceedings of the Institution of Civil Engineers: Engineering Sustainability*, *169*(6), 243–252. https://doi.org/10.1680/JENSU.15.00032
14. De Bem Machado, A., Dos Santos, J. R., Sacavém, A., & Sousa, M. J. (2023). Digital transformation: Management of smart cities. In *Smart Cities and Digital Transformation: Empowering Communities, Limitless Innovation, Sustainable Development and the Next Generation* (pp. 59–83). Emerald Group Publishing Ltd. https://doi.org/10.1108/978-1-80455-994-920231004
15. De Jong, M., Joss, S., Schraven, D., Zhan, C., & Weijnen, M. (2015). Sustainable–smart–resilient–low carbon–eco–knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization. *Journal of Cleaner Production*, *109*, 25–38. https://doi.org/10.1016/J.JCLEPRO.2015.02.004
16. Eldafrawi, M., Varghese, K. K., Afsari, M., Babapourdijojin, M., & Gentile, G. (2024). *Machine Learning-Enhanced Conformal Prediction Approach for Road Traffic Accident Severity Assessment: A Case Study of Rome*. https://doi.org/10.2139/SSRN.4679159
17. Esfandi, S., Tayebi, S., Byrne, J., Taminiau, J., Giyahchi, G., & Alavi, S. A. (2024). Smart Cities and Urban Energy Planning: An Advanced Review of Promises and Challenges. In *Smart Cities* (Vol. 7, Issue 1, pp. 414–444). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/smartcities7010016
18. Gazzola, P., Del Campo, A. G., & Onyango, V. (2019). Going green vs going smart for sustainable development: Quo vadis? *Journal of Cleaner Production*, *214*, 881–892. https://doi.org/10.1016/J.JCLEPRO.2018.12.234
19. Gjorgievski, V. Z., Markovska, N., Mathiesen, B. V., & Duić, N. (2022). Smart energy demand for the sustainable development of energy, water and environment systems. *Smart Energy*, *8*, 100091. https://doi.org/10.1016/J.SEGY.2022.100091
20. Gonzalez Venegas, F., Petit, M., & Perez, Y. (2021). Active integration of electric vehicles into distribution grids: Barriers and frameworks for flexibility services. *Renewable and Sustainable Energy Reviews*, *145*, 111060. https://doi.org/10.1016/j.rser.2021.111060

21. Govada, S. S., Spruijt, W., & Rodgers, T. (2017). Smart City Concept and Framework. *Advances in 21st Century Human Settlements*, 187–198. https://doi.org/10.1007/978-981-10-1610-3_7
22. Gürdür Broo, D., Bravo-Haro, M., & Schooling, J. (2022). Design and implementation of a smart infrastructure digital twin. *Automation in Construction*, *136*, 104171. https://doi.org/10.1016/J.AUTCON.2022.104171
23. Han, M. J. N., & Kim, M. J. (2024). A systematic review of smart city research from an urban context perspective. *Cities*, *150*, 105027. https://doi.org/10.1016/J.CITIES.2024.105027
24. Haydari, A., & Yilmaz, Y. (2022). Deep Reinforcement Learning for Intelligent Transportation Systems: A Survey. *IEEE Transactions on Intelligent Transportation Systems*, *23*(1), 11–32. https://doi.org/10.1109/TITS.2020.3008612
25. Hurlimann, A., Moosavi, S., & Browne, G. R. (2021). Urban planning policy must do more to integrate climate change adaptation and mitigation actions. *Land Use Policy*, *101*, 105188. https://doi.org/10.1016/J.LANDUSEPOL.2020.105188
26. Javed, A. R., Shahzad, F., Rehman, S. ur, Zikria, Y. Bin, Razzak, I., Jalil, Z., & Xu, G. (2022). Future smart cities requirements, emerging technologies, applications, challenges, and future aspects. *Cities*, *129*. https://doi.org/10.1016/J.CITIES.2022.103794
27. Jiang, H. (2021). Smart urban governance in the 'smart' era: Why is it urgently needed? *Cities*, *111*, 103004. https://doi.org/10.1016/J.CITIES.2020.103004
28. Kondiba, V., & Kothalanka, A. (2023). Smart City Sustainability Based on IoT Technologies and Applications. *Smart Innovation, Systems and Technologies*, *363*, 323–334. https://doi.org/10.1007/978-981-99-4717-1_30
29. Lee, J., Babcock, J., Pham, T. S., Bui, T. H., & Kang, M. (2023). Smart city as a social transition towards inclusive development through technology: a tale of four smart cities. *International Journal of Urban Sciences*, *27*(S1), 75–100. https://doi.org/10.1080/12265934.2022.2074076
30. Meng, X., & Zhu, L. (2024). Augmenting cybersecurity in smart urban energy systems through IoT and blockchain technology within the Digital Twin framework. *Sustainable Cities and Society*, *106*, 105336. https://doi.org/10.1016/J.SCS.2024.105336
31. Pacheco, J., & Hariri, S. (2016). IoT security framework for smart cyber infrastructures. *Proceedings - IEEE 1st International Workshops on Foundations and Applications of Self-Systems, FAS-W 2016*, 242–247. https://doi.org/10.1109/FAS-W.2016.58

32. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T., Mulrow, C. D., Shamseer, L., & Moher, D. (2020). Mapping of reporting guidance for systematic reviews and meta-analyses generated a comprehensive item bank for future reporting guidelines. *Journal of Clinical Epidemiology*, *118*, 60–68. https://doi.org/10.1016/J.JCLINEPI.2019.11.010
33. Russo, A. (2025). Towards Nature-Positive Smart Cities: Bridging the Gap Between Technology and Ecology. *Smart Cities 2025, Vol. 8, Page 26*, *8*(1), 26. https://doi.org/10.3390/SMARTCITIES8010026