DOCTORAL THESIS

From Challenge to Opportunity: Governance as Both Obstacle and Solution to Inclusive Smart Cities

Dominik Beckers

TALLINNA TEHNIKAÜLIKOOL
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DOMINIK BECKERS

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TALLINN UNIVERSITY OF TECHNOLOGY
School of Engineering
Department of Civil Engineering and Architecture
Academy of Architecture and Urban Studies
FinEst Centre for Smart Cities
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Supervisor: Prof. Luca Mora
Academy of Architecture and Urban Studies:
Department of Civil Engineering and Architecture
Tallinn University of Technology
Tallinn, Estonia

Opponents: Prof. Matthias Fink
Institute of Innovation and Management
Johannes Kepler University Linz
Linz, Austria

Prof. Joep Crompvoets
Public Governance Institute
KU Leuven
Leuven, Belgium

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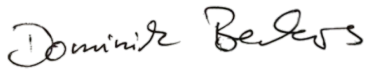
Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted

Dominik Beckers



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Väljakutsest võimaluseni: valitsemine kui takistus ja lahendus kaasavatele tarkadele linnadele

DOMINIK BECKERS

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List of Publications

The list of author's publications, on the basis of which the thesis has been prepared:

I Haque, M. N., **Beckers, D.,** Costales, E., Aad, S., Sharifi, A., Mora, L. (2025). "A systematic review of research on just, equitable, responsible, and inclusive smart cities." Technology in Society 83: 103050. (ETIS Category: 1.1.)

II **Beckers, D.** and Mora, L. (2025). "Overcoming the Smart City Governance Challenge: An Innovation Management Perspective." Journal of Urban Technology: 1–22. (ETIS Category: 1.1)

III **Beckers, D.**, Mora, L., Platania, F., Gerli, P. (2026). "There Is No Rose Without a Thorn: Examining the Contribution of Collaborative Platforms to Sustaining Collaborative Governance." Governance 39(1): e70090. (ETIS Category: 1.1)

IV Chen, W., Lu, H., Mora, L., Chen, T., **Beckers, D.**, Hu, M. (2025). "Linking manufacturing digitalization and technological Innovation: The mediating role of dynamic capabilities." Technology in Society 83: 103041. (ETIS Category: 1.1)

Author's Contribution to the Publications

Contribution to the papers in this thesis are:

I In **Article I**, the author screened over 100 articles and conducted full-text reviews of more than 30 articles that contributed to the manuscript, which presents a systematic literature review investigating the notion of justice in smart city research, with a particular focus on governance. The author helped develop the criteria used for reviewing these articles. In addition, the author took the lead in analysing the collected data and wrote substantial sections of the manuscript, including the introduction, theoretical framework, results, discussion, and conclusion. The author also played a leading role throughout the review process leading up to publication.

II In **Article II**, the author of this thesis is the first author. Accordingly, the author took the lead in identifying critical issues within the theoretical domain of smart city governance by reviewing relevant literature in this field. In addition, the author identified theories from innovation management studies that have the potential to address the deficiencies in our current theoretical understanding of smart city governance. The author also was the leading figure in drafting and reviewing the manuscript throughout the entire submission and revision process.

III In **Article III**, the author of this thesis is the first author. In this role, the author co-developed the survey used for data collection and managed the data collection process. Furthermore, the author developed the theoretical framework and interpreted the data, which allowed him to also draft the discussion section of the final manuscript. The author also took the lead in writing and reviewing all sections of the manuscript and was responsible for addressing the reviewers' comments prior to publication.

IV In **Article IV**, the author of this thesis contributed to the publication by co-developing the theoretical framework on which the subsequent analysis is based. Specifically, the author reviewed literature on the concept of dynamic capabilities, exploring the mediating role of dynamic capabilities in the innovation practices of private actors. Based on this review, the author contributed to the development of the theoretical framework and to the formulation of the discussion section of the manuscript.

1. Focus and Aim

This doctoral dissertation argues that the sustainability of smart cities depends less on technology itself and more on how smart cities are governed, making governance both an inherent obstacle and a potential opportunity.

Smart cities have gained prominence and aim to address complex urban challenges through digital technologies and innovation. However, while technological solutions often take centre stage, a growing body of evidence suggests that governance is the crucial, and often underdeveloped, dimension determining the success or failure of smart city initiatives. Governance defines how decisions are made, how responsibilities are distributed, or how collaboration unfolds among the diverse actors shaping smart cities.

This dissertation positions smart city governance as the central analytical focus. Rather than treating governance as a background condition, it investigates it as both a source of challenge and a pathway toward more effective smart city implementation. Across four interrelated studies, the thesis explores how governance arrangements are conceptualised, practiced, and experienced in the context of smart city development.

Together, these studies build the foundation for the dissertation's central argument: governance is both a problem and a potential solution in smart city development. Conceptual ambiguity, stakeholder misalignment, and coordination failures often stem from weak or inappropriate governance models. At the same time, innovation in governance, whether through theory, institutional design, or platform arrangements, for instance, holds potential for improving the outcomes of smart city projects.

Moreover, this thesis highlights collaboration as a key condition for smart city development and crucial element for effective smart city governance. The quadruple helix model, which brings together governments, academia, industry, and citizens (see Thabit & Mora, 2023), highlights how smart cities depend on the combined contributions of diverse actors to address complex challenges.

This thesis aims to address persistent gaps that characterise the current state of research on smart city governance. While the body of smart city literature has grown over the past decades (see Section 2.1 of this thesis), few studies have offered a comprehensive account of the changes needed in governance mechanisms to support sustainable urban transitions. Existing research has not yet succeeded at providing theoretical frameworks that capture the key dimensions of governance in smart city projects (see Khan et al., 2020; Mora et al., 2020; Ruohomaa et al., 2019). At the same time, policymakers and other stakeholders lack practical, research-based recommendations that could guide long-term strategies for implementing smart and sustainable cities (see Chaffin et al., 2014; Lee et al., 2014; Viale Pereira & Schuch de Azambuja, 2021). This disconnect between theory and practice is oftentimes reflected in fragmented planning and execution, where traditional governance models tend to prove ill-suited to the demands of digital transformation in urban spaces (see Ooms et al., 2020; Razaghi & Finger, 2018; Ruhlandt, 2018).

This thesis employs a combination of empirical investigations and theoretically grounded discussions, forming a concerted effort to contribute to both practice and theory.

Article I, co-authored with Dr. Nazmul Haque, Dr. Emilio Costales, Prof. Samar Aad, Prof. Ayyoob Sharifi and Prof. Luca Mora, presents a systematic literature review investigating how justice-related issues are addressed in smart city governance research. Drawing on 67 peer-reviewed empirical studies, the article maps how themes such as

inclusivity, responsibility, equity, and ethics are represented in the smart city literature. The findings show that justice is often treated as a secondary concern, with many studies lacking explicit conceptual frameworks or consistent terminology. The review identifies significant gaps in empirical attention to underrepresented groups and key dimensions of justice, including procedural and recognitional justice. The article contributes to the field of smart city governance by offering a structured synthesis of justice-related themes and proposing a future research agenda to better integrate justice into smart city governance studies. This original piece of research is primarily concerned with the **perspective of citizens** in smart city collaborations.

Article II, co-authored with Prof. Luca Mora, is a conceptual viewpoint paper that examines limitations in current governance frameworks in smart city development and proposes a new research trajectory informed by innovation management theory. The article argues that existing approaches to governing smart cities are often fragmented, techno-centric, and lacking in theoretical clarity. Drawing on concepts from innovation studies such as strategic alignment, boundary management, and intermediation, the article outlines how governance research can be advanced. Its contribution lies in highlighting current theoretical gaps in our understanding of smart city governance that impact smart city practice as well as setting out a cross-disciplinary agenda that encourages new theoretical approaches to studying governance in the context of urban digital innovation. This original research is primarily concerned with the **academic perspective**, representing academics' ambition to build the theoretical foundations of smart city governance.

Article III, co-authored with Prof. Luca Mora, Prof. Federico Platania and Prof. Paolo Gerli, explores how collaborative platforms contribute to governance practices in smart city initiatives. Based on a global survey of 289 smart city experts from 65 countries, including municipal government officials and academic experts involved in local smart city initiatives, the article tests eight hypotheses relating to various dimensions of collaborative governance. Using multinomial logit modelling, the findings show that collaborative platforms can support knowledge sharing and strategic orientation, but their influence is less clear in areas such as innovation culture, internal coordination, and coordination across levels of government. In some cases, municipalities without such platforms perform as well or better than those with them. The article contributes new empirical evidence on the contribution of collaborative platforms in smart city governance and smart city collaborations. In doing so, by investigating municipally led collaborative platforms, this article reflects the perspective of the **public sector**.

Article IV, co-authored with Prof. Weimin Chen, Prof. Haiyan Lu, Prof. Luca Mora, Prof. Ting Chen, and Prof. Mengyun Hu, investigates the relationship between manufacturing digitalisation, dynamic capabilities, and technological innovation in Chinese manufacturing firms. Drawing on survey data from 276 firms in 30 designated pilot cities, the article uses confirmatory factor analysis and multiple regression models to test the proposed relationships. The findings show that digitalisation significantly enhances product and process innovation and that this effect is (partially) mediated by a firm's capacity to sense, seize, and reconfigure resources and thereby employ its dynamic capabilities. The article contributes to the broader governance and innovation literature by highlighting the role of organisational capabilities in shaping technological outcomes within the context of digital transformation. In this way, the article takes the perspective of **private actors** in smart city collaborations.

This thesis is organised around four overarching research objectives, each addressing a core aspect of smart city governance (see Table 1). Objective A focuses on understanding the nature of the governance challenges that constrain smart city development in both theory and practice. This objective is informed by Article I and Article II. Article I, a systematic review of justice in smart city research, demonstrates that deficiencies in governance arrangements can produce a range of adverse societal effects, including the marginalisation of vulnerable groups, unequal access to infrastructure and services, and limited inclusion in participatory processes. While centred on justice, the article's broader implication is that such outcomes are symptomatic of governance frameworks lacking elements such as inclusiveness, clarity, and accountability. Article II identifies foundational weaknesses in the way smart city governance is currently theorised. Among other elements, it highlights vague definitions, fragmented coordination mechanisms, and an overreliance on techno-centric approaches that neglect the socio-institutional complexities of urban innovation. Together, these articles offer a critical diagnosis of the limitations embedded in current governance models and emphasise the need for a more nuanced and theoretically grounded perspective. All insight pertaining to Objective A are presented in Section 4.1. of this thesis.

Objective B turns to the practical implications of governance design, asking how various approaches to smart city governance may (not) help address societal needs, manage collaboration, and navigate fast-changing environments, thereby aiming to sketch a way forward towards more effective smart city governance. It addresses three interrelated concerns. Article I offers a broad overview of how justice-related issues have been treated in empirical smart city research. The review identifies significant conceptual and practical gaps, reinforcing the argument that governance frameworks must move beyond efficiency and innovation to embrace equity, accountability, and inclusiveness. Article III investigates municipally led collaborative platforms as institutional mechanisms for coordinating smart city projects. The findings show that, even within intentionally designed organisational settings, challenges and uncertainties persist, thereby underscoring that governance design is not a peripheral issue but a central determinant of effective smart city implementation. Article IV examines the relationship between manufacturing digitalisation, dynamic capabilities, and technological innovation. It finds that dynamic capabilities, i.e. the ability to sense, seize, and reconfigure resources, are essential for private firms to contribute meaningfully to smart city innovation. This insight broadens the governance discussion to include questions of organisational adaptability and capacity-building. Objective B is addressed in Section 4.2 of this thesis and its subsections.

Objective C seeks to contribute to theory development by identifying and integrating relevant conceptual tools from adjacent streams of literature that promise to bear the potential to enhance the study of smart city governance. Leaning on the field of Innovation Management Studies, Article II introduces key concepts such as strategic orientation, intermediation, and boundary management as tools for addressing coordination and leadership challenges in governance processes. Article III also contributes to theoretical development by integrating and applying Collaborative Governance concepts. Collectively, these theoretical contributions lay the groundwork for a more integrative and cross-disciplinary approach to understanding and improving governance in smart city contexts. All insights related to Objective C are presented in Section 5.1 of this thesis and its corresponding subsections.

Objective D reflects the attempt to formulate key principles that complement existing conceptualisations of smart city governance and inform future theoretical and practical approaches towards governing smart city projects. Synthesising the results of the four articles included in this thesis, three principles crystallise: sociotechnical, inclusive, and temporal. The sociotechnical principle stresses that governance must integrate technological infrastructures with societal needs and institutional arrangements. The inclusive principle highlights the need to confront power imbalances and embed justice, transparency, and participation into governance design. The temporal principle emphasises adaptability, reflexivity, and long-term orientation in response to changing circumstances. Section 5.2 and its subsections present the insights that address Objective D.

Taken together, the four objectives form a coherent analytical progression. The thesis begins by identifying and problematising governance challenges, proceeds by offering empirically grounded insights into how contemporary governance arrangements may (not) support inclusive, adaptive, and collaborative smart city initiatives, continues with proposing cross-disciplinary conceptual tools and insights to strengthen theoretical understanding, and concludes by presenting core principles that are intended to guide smart city governance theory and practice in the future.

Table 1. Objectives Pursued by this Thesis.

	Objectives	**Article I**	**Article II**	**Article III**	**Article IV**
A	Understand the smart city governance challenges	X	X		
B	Explore how different approaches to smart city governance can help address societal needs, manage collaboration, and navigate fast-changing environments in order to inform more effective governance design	X		X	X
C	Contribute to strengthening theoretical foundations for smart city governance by means of a cross-disciplinary approach		X	X	
D	Formulate key principles of smart city governance	X	X	X	X

The remainder of the thesis is organised as follows. First, the analytical framework of the thesis is outlined. Second, the research methodology is presented. Third, the key findings are summarised. Fourth, a synthesising discussion is offered. Fifth, concluding remarks including theoretical and practical contributions as well as limitations of this thesis and potential avenues for future research are laid out. Lastly, the four original works included in this thesis are featured and complemented by an abstract and CV of the author.

2. Analytical and Conceptual Framework

2.1. Smart City

The idea of the smart city has its roots largely in industrial innovation and private-sector initiatives, where technological advancement is positioned as the main catalyst for urban change (Guma & Monstadt, 2021). This technology-first approach has for many years shaped both academic discourse and policy practice in the field (Gil-Garcia et al., 2015). Examining the evolution of smart city models, Mora and Deakin (2019) observe that much of the literature on smart cities adopts a techno-centric stance, viewing smart cities primarily as outcomes of technologies being implemented in urban systems, with information and communication technologies (ICT) and market-driven dynamics seen as the primary forces driving urban development.

However, although technological and digital innovations are critical for advancing smart city development, the prevailing emphasis on infrastructure and technical solutions has oftentimes fostered a vision that tends to serve the interests of technology providers more than those of citizens and other city users. Such an approach risks neglecting broader public value, including quality of life and social equity (Lepore et al., 2023). As Voorwinden and Ranchordas (2021, p. 8) caution, in cities where the smart city model is framed predominantly through a technology-centric lens, "socio-economic disparities [may] continue to worsen," exacerbating existing inequalities rather than alleviating them. Several scholars echo this sentiment and have been critically eyeing the concept of smart cities as well as its practical implementations. For instance, Söderström et al. (2014) contend that a smart city is merely the product of "corporate storytelling" (p. 307) and technology providers' marketing campaigns, while Nam and Pardo (2011) argue that the concept of a smart city represents little more than conventional urban innovation under a new label.

In response to this often-witnessed techno-centricity, various scholars have started advocating for a more socially-oriented conceptualisation and approach to implementing smart cities. For instance, Kim et al. (2021, p. 13) argue that "technological aspects [of smart cities] are tightly interlocked with social systems which are outcomes of historically and culturally accumulated social innovations," and Albino et al. (2015, p. 4) emphasise that "the concept of the smart city is far from being limited to the application of technologies to cities." Mora and Deakin (2019) reflect this growing, albeit still limited, body of literature that challenges the dominant techno-centric perspective and instead promotes a more holistic vision of smart cities. In this view, smart cities are not conceived merely as technological fixes achieved by embedding ICT solutions into urban infrastructure, but as technological development that is integrated with human, social, cultural, economic, and environmental considerations, thereby highlighting social priorities in both scholarly debate and practical implementation of smart city development.

While no universally agreed definition of the smart city concept exists to date, scholars have started to develop a range of conceptualisations that echo this increasing attention to social considerations and demonstrate different disciplinary perspectives and priorities. Many definitions emphasise the use of information and communication technology (ICT) to improve the quality of life of citizens, enable sustainable urban development, optimise resource use, and enhance public services, often alongside fit-for-purpose infrastructure and effective governance arrangements (see Ismagilova et al., 2019; Samarakkody et al., 2019). Others emphasise more explicitly the importance

of human capital and its mobilisation and utilisation through collaboration between various actors (see Komninos, 2014; Meijer & Bolívar, 2015). Further interpretations approach the smart city concept from a more systems-oriented perspective, highlighting the interplay between technology, governance, economy, environment, mobility, and living to foster innovation and long-term sustainability (see Anthopoulos et al., 2019; Samih, 2019).

To implement the smart city concept in practice, various actors may initiate a series of projects that typically involve deploying technologies designed to stimulate urban innovation processes, enhance the delivery of urban services, and ultimately improve citizens' quality of life (Bjørner, 2021; Mora et al., 2021). Collectively, these projects denote a process that represents a specific type of urban innovation characterised by its long-term nature, context dependency, multi-dimensional scope, and systemic approach to urban and digital development (Mora et al., 2023).

In light of the wide range of existing definitions and conceptual foci, this thesis adopts the following synthesised interpretation of the smart city concept:

A smart city can be understood as an evolving urban innovation framework that integrates digital technologies, skilled human capital, and suitable governance arrangements to improve the socioeconomic and environmental conditions of citizens and other city users. The adjective of smart is not viewed as a binary state of "being smart" or "not being smart," but rather as a continuum in which local governments, citizens, private actors, and academics undertake initiatives aimed at progressively enhancing urban living. By embedding information and communication technologies across key sectors such as transport, energy, waste management, healthcare, safety, housing, and education, smart cities seek to address inefficiencies, foster cross-sectoral integration, and adapt urban systems to contemporary challenges. Ultimately, the smart city concept aspires to transform urban models into more efficient, inclusive, and resilient forms of urban development.

In the central definition adopted for this thesis governance plays an important role as a connecting element between different smart city projects, administrations, or external stakeholder groups, for instance (Albino et al., 2015; Pereira et al., 2018). It is through effective governance that "technology can act as an enabler to improve the life of citizens rather than expecting technology by itself to engender change" (Ismagilova et al., 2019, p. 3). Therefore, the following section delves deeper into the concept of governance.

2.2. Governance

Governance has gained popularity in both practical and academic public policy discourse because of its capacity to connect with a wide range of arguments and theoretical concepts (Asaduzzaman & Virtanen, 2016). At its core, the concept of governance refers to the processes and institutional arrangements through which public goals are pursued and complex societal challenges are addressed, often involving a range of actors beyond traditional, centralised structures of public authority (Bingham et al., 2005). Unlike government, which tends to be characterised by formal authority, hierarchical bureaucracy, legal enforcement, and regulatory control, governance denotes a more decentralised, networked form of coordination. It encompasses the creation, execution, and implementation of activities supported by shared objectives among diverse participants (Gjaltema et al., 2020). Governance involves increasing reliance on nonregulatory policy instruments, such as voluntary agreements, partnerships, and collaborative arrangements, where "quasi- and nonstate actors" (MacLeod & Goodwin,

1999, p. 506) contribute to the development and implementation of public policy (Voorwinden & Ranchordas, 2021). Rather than working in isolation from one another, governance is defined by the collective engagement of various domains and sectors (Wang & Ran, 2023). This shift "from government to governance" (Mayntz, 2017, p. 18), which has also been dubbed as "governance-beyond-the-state" (Swyngedouw, 2005, p. 1991), reflects a broader trend in which networks involving public bodies, private sector organisations, academics, and civil society actors, collaboratively participate in the design and delivery of public services and creation of public value (Thabit et al., 2024). These arrangements are commonly polycentric in nature, characterised by the diffusion of power and decision making across multiple scales and sectors (Hajer, 2003). As such, the concept of governance represents both a practical and conceptual reconfiguration of how authority is exercised and how collective action is organised in our contemporary society (Katsamunska, 2016).

2.2.1. Collaborative Governance

As "governments alone cannot meet the enormous challenges of the day" (Florini & Pauli, 2018, p. 586), collaboration is central in governance. In response, scholars have championed the concept of collaborative governance, which can generally be referred to as the processes and structures through which public policy decisions and management are conducted by engaging external actors across organisational, administrative, and sectoral boundaries and levels (Emerson & Nabatchi, 2015; Emerson et al., 2011). Collaborative governance refers to representative, consensus-oriented, and deliberative forms of collective decision-making in which stakeholders co-produce goals, strategies, and actions, while sharing responsibilities and resources (Ansell & Gash, 2008). These arrangements often involve cooperation both vertically, between actors operating at local, regional, national, and supranational levels, and horizontally, across jurisdictions and sectors at the same level, with resources flowing in both directions (Borgström, 2019; Ehnert et al., 2018). Collaborative governance is believed to be particularly relevant for addressing challenges that cut across jurisdictional boundaries and require cross-sectoral exchange of resources or capabilities, enabling more context-sensitive, locally responsive, and collectively supported solutions (Lee, 2021; Peters & Pierre, 2001). In these contexts, no single actor or level possesses all the authority or resources required to address complex issues, creating mutual dependency and a need for shared responsibility (Stephenson, 2013). Collaborative governance is therefore often understood as a toolbox encompassing a range of mechanisms such as informal sharing arrangements, public–private partnerships, joint power agreements, participatory planning processes, or stakeholder advisory groups, either used independently or in combination, to address complex public problems (Scott & Thomas, 2017).

Collaborative governance is further intended to help institutionalise approaches to coordinating and facilitating cooperation among actors with heterogeneous interests and resources (Zhou & Dai, 2022). It seeks to promote equitable participation in decision-making, ensuring that the voices of local communities and affected stakeholders are heard when decisions are being made and projects implemented (Piattoni, 2009). Moreover, collaborative governance also aims to build a degree of "institutional thickness" (MacLeod & Goodwin, 1999, p. 512) that supports local economic, social, and cultural developments, by enabling strong institutional presence, interaction among stakeholder groups, coalition-building, and the development of a shared understanding of the goals and implementation mechanisms to be pursued; As Ciasullo et al. (2020, p. 1171)

claim, “successful [collaborative] governance lies in the capability to mediate between conflicting interests and harmonize the stakeholders’ objectives with overall systems goals.“

However, “the growing use of collaborative methods of governance [inadvertently] raises concerns about the relative power of participants in such processes and the potential for exclusion or domination of some parties” (Purdy, 2012, p. 409). Power imbalances among collaborators can allow more influential actors to shape or dominate the collaborative process, thereby undermining the overall effectiveness of the collaboration (Choi & Robertson, 2013; Kruhlov et al., 2024; Ran & Qi, 2017). Individual or few collaborating partners might attempt to exercise influence to “power over” others with the intention of pursuing self-driven interests rather than those of the collaboration (Huxham & Vangen, 2005). Such tendencies stand in stark contrast to the fundamental principles of collaborative governance, which aims to facilitate collective action that leads to mutual gain (“power to”) and allows all stakeholder groups that are affected by a decision to participate in the underlying processes leading to said decision (“power for”) (Purdy, 2012). As a consequence, stakeholder groups with limited influence and means or lower perceived legitimacy may risk being marginalised in collaborative processes or having their participation co-opted by more dominant stakeholders (O'Toole Jr & Meier, 2004). This, in turn, may lead to what Bulkeley (2005, p. 894) termed the “hollowing out of the state,” where democratic principles are compromised.

These dynamics can have implications for perceptions of justice in governance arrangements. Justice is a central principle in governance, serving as a safeguard against the risk that institutional arrangements reinforce or exacerbate inequalities. Instead, it calls for the promotion of inclusivity, fairness, and ethical decision-making in the design and implementation of policies and projects (Sikor et al., 2014). Haque and Sharifi (2024a) distinguish between justice types and justice dimensions as complementary analytical tools for examining justice in governance. Justice types identify the domains where justice concerns may emerge, such as environmental justice, which ensures that environmental benefits and burdens are shared fairly and that vulnerable communities are protected from disproportionate negative impacts; social justice, which relates to equitable access to resources and opportunities; mobility justice, which focuses on enabling societal participation and improving quality of life through equitable transport and mobility opportunities; ecological justice, which advocates for protecting ecosystems and non-human entities; and infrastructural justice, which seeks to rectify historical inequalities embedded in outdated or unevenly distributed infrastructure (Calderón-Argelich et al., 2021; Haque & Sharifi, 2024a; Pineda-Pinto et al., 2022; Schlosberg, 2013; Zuniga-Teran et al., 2021). Justice dimensions, by contrast, serve to capture the processes through which justice is operationalised in governance arrangements. Distributional justice addresses the fair allocation of benefits, burdens, infrastructure, resources and services; procedural justice emphasises inclusivity, transparency, and fairness in decision-making; recognitional justice calls for acknowledging and integrating the perspectives and needs of diverse social groups; and restorative justice is concerned with correcting historical exclusions and inequalities (Anguelovski et al., 2020; Calderón-Argelich et al., 2021; Haque & Sharifi, 2024a; Langemeyer & Connolly, 2020; Schlosberg, 2013; Zuniga-Teran et al., 2021).

2.2.2. Collaborative Platforms

To address shortcomings in collaborative governance arrangements and concerns regarding justice within them, various scholars have been promoting the concept of collaborative platforms (see Hafer et al., 2024; Nambisan, 2009). Collaborative platforms can be understood as "an organization or program with dedicated competencies, institutions, and resources for facilitating the creation, adaptation, and success of multiple or ongoing collaborative projects or networks" (Ansell & Gash, 2018, p. 20). In practice, collaborative platforms are increasingly recognised as a distinct mode of governance designed to facilitate collaborative governance arrangements (Bizzo & Michener, 2024; Lee, 2022). They strive to provide a stable institutional space that enables, coordinates, and, to some extent, regulates "many-to-many collaborative relationships" (von Heimburg et al., 2023, p. 27) through multiple concurrent collaborative projects or networks among diverse stakeholders (Bizzo & Michener, 2024).

Unlike short-term partnerships, collaborative platforms are intended to serve as long-lasting and stable governance infrastructures, offering resources, including administrative and technical expertise, or funding, as well as procedural frameworks, such as decision-making rules, participation guidelines, and coordination mechanisms (Bell & Scott, 2020; Scott & Thomas, 2017). In doing so, collaborative platforms are expected to navigate diverse and sometimes fragmented interests among various actors into more coherent, integrated, and strategically aligned efforts (Zhou & Dai, 2022). As such, collaborative platforms fulfil functions that innovation management scholars would associate with "strategic intermediaries" (Moss, 2009) and "systemic intermediaries" (van Lente et al., 2003); They operate at the intersection of multiple networks and systems and can serve to translate overarching strategies into local collaborative governance arrangements by aligning organisational structures with technological and resource capacities (Lee, 2022). Through this process, collaborative platforms may provide both horizontal and vertical intermediation. Horizontally, they can help pool and coordinate the inputs of diverse stakeholder groups to coordinate action (Sapraz & Han, 2021). Vertically, they may link local initiatives to broader national or international political and administrative levels, narratives, and resources (Zhou et al., 2021).

Collaborative platforms may operate as independent organisations or function as dedicated subunits within a larger organisation, for instance (Ansell & Gash, 2018). They can exist as physical spaces, virtual interfaces, or hybrid arrangements, enabling both face-to-face and digitally mediated collaboration (Recalde et al., 2020). Design features such as size, leadership structure, or other internal governance arrangements are dependent on the specific context within which collaborative platforms operate, the scale of governance they adhere to, the objectives they pursue, or the composition of participating actors, for instance (Bell & Scott, 2020; Kilelu et al., 2013).

Collaborative platforms represent an organisational logic that is intended to promote and sustain collaborative governance (Ansell et al., 2025). They act as an enabling environment and ecosystem where stakeholders co-create public value while also pursuing their own objectives, often aiming to align knowledge, technical expertise, and institutional capacity to achieve outcomes that no single actor could realise alone. By embedding collaboration into a structured yet adaptable institutional setting, these platforms contribute to the scaling, resilience, and long-term viability of collaborative

projects, making them a potentially powerful instrument for addressing complex, cross-sectoral, and multi-actor governance challenges (Ansell & Torfing, 2015; Farstad et al., 2022).

2.2.3. Dynamic Capabilities

"Governance success is intimately linked to policy success and, therefore, to policy capacity" (Howlett & Ramesh, 2016, p. 302). Pierre (1999) further contend that understanding the capabilities of collaborating organisations is crucial for an understanding of governance. As a consequence, the success of governance arrangements depends on the capabilities of the various actors that contribute to them as well as how effectively they provide, combine and employ these capabilities (Clarke & Ramirez, 2014); Capabilities are an indispensable element to develop and manage among partners participating in collaborative governance arrangements. As Chaskin (1999, p. 3) argues, capabilities are what create "communities that 'work'; it is what makes well-functioning communities function well" and enables actors to mobilise resources, pursue individual and communal goals, and strengthen governance arrangements (Hall, 2002).

Interactions between collaborating partners have demonstrated their potential to generate knowledge and facilitate learning, both of which are crucial for building capabilities within and across collaborating actors. Partner organisations frequently seek to broaden their base of capabilities, which may take the form of co-specialised or complementary skills that contribute to the success of joint projects (Bosch-Sijtsema & Postma, 2009). Indeed, capabilities are developed over time through the participation in collaborative projects, yet they depend on the surrounding governance arrangements shaping these projects. Conducive governance can foster the evolution of mutually beneficial capabilities, whereas rigid or poorly designed governance structures may hinder this process (Heaton et al., 2023). Capabilities can therefore be viewed as both a prerequisite for initiating and sustaining collaboration as well as an outcome that emerges from such collaborative processes (Leach et al., 2013).

Since governance is defined in this thesis as a dynamic process, capabilities must also be understood as dynamic in order to keep pace with the accelerating demands of our society. Governance systems operate in environments shaped by fast-changing societal needs, uncertain technological developments, and competing interests. In such contexts, static capabilities are insufficient to ensure long-term effectiveness (Teece et al., 2016). The value of existing capabilities and their combinations may diminish when they lose alignment with changing societal or technological conditions. To remain effective and legitimate, governance systems must therefore refine, adapt, and renew their capabilities continuously, maintaining coherence with evolving challenges and opportunities (Wilden et al., 2013).

Dynamic capabilities are broadly defined as the ability of an organisation to integrate, build, and reconfigure internal and external knowledge resources in order to respond to rapidly changing environments (Teece et al., 1997). They constitute the strategic routines and processes through which organisations renew their competences, adapt to uncertainty, and maintain long-term effectiveness (Mahoney & Kor, 2015). Teece (2007) emphasises that dynamic capabilities rest on three interrelated dimensions: sensing opportunities and threats, seizing them through investment and innovation, and reconfiguring existing resources and structures to ensure ongoing alignment with evolving contexts. Building on this, Wang and Ahmed (2007) distinguish absorptive

capacity (integrating external knowledge), innovative capacity (mobilising resources for new products and processes), and adaptive capacity (flexibly adjusting strategies and structures).

The concept of dynamic capabilities is rooted in, yet extends beyond, the resource-based view (RBV) of the firm. The RBV conceives organisations as bundles of resources and capabilities (Wernerfelt, 1984) and holds that competitive advantage stems from resources that are valuable, rare, inimitable, and non-substitutable (Barney, 2001). While this perspective highlights the strategic importance of resources, it has been criticised for its static nature and limited ability to explain adaptation in fast-changing environments (Kraaijenbrink et al., 2010; Priem & Butler, 2001). Dynamic capabilities address this gap by emphasising the processes through which organisations continuously reconfigure and renew their resources and capabilities to sustain competitiveness. In this way, dynamic capabilities can be understood as an extension of the RBV that shifts the focus from possession of resources to the ongoing ability for adaptation and renewal (Helfat & Peteraf, 2003).

Dynamic capabilities are especially pertinent in the context of digitalisation. Digital innovation requires more than the adoption of new technologies. It demands the ability to continuously adjust organisational structures, processes, and resource allocations in response to shifting technological and market conditions (Helfat & Raubitschek, 2018). Dynamic capabilities can enable organisations to sense opportunities created by digital tools, seize them through innovation, and reconfigure existing assets to align with demands of digitalisation (Ahn et al., 2022). As such, dynamic capabilities not only underpin governance effectiveness but also determine whether organisations can turn digitalisation into a sustained competitive advantage, particularly in the current era of rapid technological change and the Fourth Industrial Revolution (Qi & Xiao, 2020).

Private companies play a central role in the context of digitalisation, as they are the primary providers of rapidly evolving digital technologies (Voorwinden & Ranchordas, 2021). Underlying the provision of these technologies is a digitalisation process that reshapes the manufacturing approaches and systems through which such technologies are developed and delivered. Digital manufacturing refers to the integration of innovations such as additive manufacturing, robotics, artificial intelligence, cloud computing, and smart sensors into production systems, thereby transforming product design, development, and operational processes (Frank et al., 2019; Savastano et al., 2022). These technologies represent disruptive innovations that increasingly replace traditional production methods (Buer et al., 2021). For private firms to respond to digitalised manufacturing, they must cultivate dynamic capabilities that enable them to sense technological trends and shifts in market conditions, seize them by embedding digital tools into their production lines, and reconfigure organisational processes and resources accordingly (Chirumalla, 2021). Digital innovation in manufacturing is not merely technological but fundamentally organisational: it requires firms to adopt new ways of working, reallocate human resources, and restructure operations to support continuous adaptation and innovation (Zhong et al., 2017). As a result, dynamic capabilities are theorised as mediating factors between the digitalisation of manufacturing and technological innovation through product and process innovation in private sector companies providing digital technologies (Wilden et al., 2013).

2.3. Smart City Governance

The emergence of what Dunleavy et al. (2006, p. 467) term the "digital era government" has prompted local authorities to integrate data-driven decision-making tools in governance processes (Barns et al., 2016). Consequently, understanding digital innovation necessitates examining how digitally enabled institutional arrangements are created, disseminated, and ultimately embedded and legitimised within wider institutional contexts (Hinings et al., 2018). By guiding the integration of new technologies into public infrastructure and urban spaces, it is through governance that digital innovation can be aligned with collective community objectives (Lopes, 2017; Micozzi & Yigitcanlar, 2022). *Smart city governance* is about employing digital tools to support innovative governance models that extend beyond traditional institutions and processes (Bolívar & Meijer, 2016; Meijer & Bolívar, 2015). At its core, smart city governance combines ICT-based tools with collaborative governance to ensure that decisions are grounded in evidence drawn from data, knowledge, and stakeholder input, thereby delivering results that respond to city users' needs (Pereira et al., 2018). Smart city governance thereby intends to function as a comprehensive framework for building new forms of collaboration through ICTs (Ciasullo et al., 2020), aiming to create adaptive and sustainable urban systems that increase public value and can respond effectively to the challenges of urban life (Meijer et al., 2016).

In an effort to capture the intricacies and dynamics of governing smart cities, Mora et al. (2023) developed a comprehensive smart city governance framework, which has also been used and adapted by Beckers et al. (2022), Beckers et al. (2023), and Mora et al. (2025). This approach to theorising smart city governance builds on three interlinked macro components: the urban strategic framework, the urban innovation ecosystem, and the urban technological infrastructure. The strategic framework encompasses policies, regulations, and institutional arrangements that steer cities towards collectively defined goals, requiring integrated planning, participatory vision-building, and flexible regulation. The innovation ecosystem brings together networks of public, private, academic, and civic actors in collaborative arrangements, relying on tools for consensus-building, participatory planning, and innovation hubs such as living labs or incubators to enable knowledge exchange and experimentation. Finally, the technological infrastructure forms the operational backbone of smart cities, comprising data architectures, platforms, and service design processes that must ensure interoperability, accessibility, and scalability.

Mora et al. (2023) thereby illustrate that smart city governance is a dynamic process of collaboration within and across levels. For instance, the very nature of the smart city concept as well as the ICTs employed in urban spaces are a-spatial and not tied to any one place, in turn urging local municipalities to use a global concept and adopt it to local context conditions and needs through governance arrangements (Angelidou, 2014). In a similar vein, smart city governance requires municipalities to balance local responsibilities with wider policy frameworks and funding mechanisms that transcend territorial boundaries (Lange & Knieling, 2020). Indeed, the policy agendas underpinning smart cities are rarely confined to the local level alone. Instead, they are shaped by conditions, objectives, and incentives that extend across regional, national, and supranational levels of governance: "policymaking centred around smart cities is at once a messy, networked process stretching across scales, while also manifesting itself in concrete practices shaped by territorial–regulatory contexts" (Varró & Bunders, 2019, p. 209). At the same time, the implementation of smart city policies and corresponding

projects depends heavily on cooperation among diverse constellations of local actors and institutions (Dameri et al., 2019). Lepore et al. (2023, p. 1) argue that as such, "smart cities should be built on Industry 4.0 technologies within a quadruple helix model involving governments, academia, industry, and citizens." This positions collaborative governance as a cornerstone of smart city development. In this context, smart cities are not only framed as the outcome of collaboration but also an active initiator of collaborative governance arrangements, increasingly expected to act as orchestrators that connect multiple actors, using mechanisms such as open data and participatory frameworks to foster collaboration and drive innovation (Tukiainen et al., 2015).

To manage such collaborations, various scholars have called for the creation of an administrative environment that facilitates collaboration between actors, and enables cities to develop dynamic capabilities, leadership, and design strategies to support their transformation towards smart cities (Calista et al., 2010; Gil-Garcia et al., 2015; Santinha & Castro, 2010; Zavadskas et al., 2010). Collaborative platforms for smart city development are believed to be a means of "contributing to a more efficient urban coordination" (Tironi & Albornoz, 2021, p. 198). Typically initiated and (co-) owned by municipal governments, these platforms are designed as institutional infrastructures with the resources and competencies to initiate, support, and sustain multiple collaborative projects for smart city development (Alam & Porras, 2018; Escobar & Henderson, 2019). They are expected to enable local governments to align stakeholders, pool resources, and steer project implementation in line with strategic goals while bridging both vertical and horizontal governance relations (Durose et al., 2019; Lepore et al., 2023). Collaborative platforms for smart city development take varied forms. Some are embedded in municipal structures, such as in Bogotá's, Colombia, mayoral office (Ochoa Guevara et al., 2019), while others operate through cross-departmental taskforces, as in Ramallah, Palestine (Mora et al., 2025). In contrast, Forum Virium Helsinki functions as a stand-alone non-profit owned by the city but operating independently, coordinating experimentation and stakeholder engagement (Shamsuzzoha et al., 2021; Soe et al., 2022).

3. Research Design and Methodology

The work carried out for this thesis was undertaken within the H2020 FinEst Twins Project, led by the FinEst Centre for Smart Cities at Tallinn University of Technology, Estonia. Since its launch in 2019, the project and its associated research centre have supported the implementation of various practically oriented initiatives aimed at co-developing smart city solutions involving city administrators, private actors, and researchers. Further efforts include national and international collaborations, consultancy projects, and a wide range of research activities, encompassing both foundational and applied research. Within this context, the FinEst Centre for Smart Cities has established several specialised research areas, one of which focuses on governance for smart city transitions. This thesis aligns with that area and contributes to strengthening the centre's research efforts in it.

This thesis consolidates four original manuscripts, all of which have been published in peer-reviewed journals indexed in Scopus and Web of Science, and all classified within the Q1 range of journal rankings and ETIS category 1.1.

Table 2 presents the various methodological approaches employed in each of the four original works, which together constitute the overall methodology of this thesis. For each publication, the main research problem, aim and purpose, research strategy, data collection methods, and stakeholder perspectives are outlined.

The following paragraphs elaborate on each publication individually, offering a more in-depth account of the methodological choices made and describing how the respective methods were implemented within the context of each study.

Table 2. Methodological Approaches Pursued in this Thesis.

	Research Issue	**Focus and Rationale**	**Research Design**	**Approaches to Data Collection**	**Stakeholder Perspectives**
I	Lack of a systematic and comprehensive framework to guide governance structures that ensure justice in smart city	Identifying the state of justice in smart city governance research and practice and identifying potential pathways for overcoming them	Systematic literature review	Systematic literature review	Citizens' perspective
II	Deficiencies in theoretical understandings of smart city governance	(i) Identifying pertinent deficiencies in theoretical constructs around smart city governance (ii) Identifying concepts stemming from innovation management studies that promise to address these deficiencies	(i) Review of conceptual literature (ii) Matchmaking of concepts stemming from innovation management studies with theoretical smart city governance challenges	Review of conceptual literature	Academic perspective (opening avenues for strengthening theoretical understanding of smart city governance)

III	Lack of understanding of the contribution of collaborative platforms to collaborative governance practices in the context of smart city development	Identifying the dimensions in which collaborative platforms can or cannot contribute to collaborative governance practices in smart city development, thereby elucidating modes of collaboration from the perspective of municipal governments	Quantitative analysis using a multinominal logit model, based on survey data	Survey distributed globally, yielding 289 responses	Public sector perspective
IV	Lack of understanding of the conditions under which, and the mechanisms through which, digitalisation enhances technological innovation in manufacturing	(i) Advancing understanding of how digitalisation influences technological innovation in manufacturing (ii) Extending dynamic capabilities theory by revealing its mediating role in the digitalisation-innovation relationship	Quantitative analysis using structural equation modelling, based on survey data	Survey distributed among Chinese manufacturing companies, yielding 276 responses	Private sector perspective

Article **I** employed a systematic literature review to investigate how justice-related issues are addressed in smart city governance research. The study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and replicability in article selection. A comprehensive search string combining terms related to smart cities and justice was developed, drawing on previous review studies. The search was conducted in the Web of Science and Scopus databases, targeting titles, abstracts, and keywords. After removing duplicates and applying inclusion criteria focused on empirical, English-language studies addressing justice in urban contexts, a total of 67 articles were selected for full-text analysis. Data extraction was guided by a deductive content analysis protocol based on an established theoretical framework. This protocol captured key information such as case location, societal groups of focus, ethical considerations, justice types and dimensions, sectoral focus, and smart city domains. Data extraction was conducted collaboratively, with quality control ensured through iterative checks and feedback among co-authors. The extracted data were organised using structured Excel spreadsheets and analysed using descriptive statistics.

Article **II** is intended to offer theoretical insights and propose new directions for research on smart city governance. In doing so, the article adopts a conceptual approach to critically examine limitations in current governance frameworks and suggest

alternatives grounded in innovation management theory. To this end, the authors reviewed a broad selection of theories and concepts from the field of innovation management and identified those deemed particularly relevant for advancing research on smart city development. The selection process was informed by the authors' interpretations of each theory's applicability to governance challenges, as well as by established academic discussions in the innovation management literature. The article aims to contribute to theory development by outlining a cross-disciplinary agenda and encouraging new approaches to the study of governance in smart city contexts.

Article **III** applied an exploratory research design to examine the role of collaborative platforms in smart city governance. The study drew on data collected through a global survey of municipal government officials involved in smart city initiatives. The survey, administered via Qualtrics between December 2021 and March 2022, was designed to test eight hypotheses concerning the relationship between collaborative platforms and key dimensions of collaborative governance. The survey was developed and validated through a multi-stage process that included extensive piloting with subject-matter experts to ensure conceptual clarity, relevance, and cross-cultural applicability. Distributed through direct outreach and smart city networks, the survey reached municipal representatives in 65 countries, yielding 289 valid responses. To analyse the data, the study employed a multinomial logit (MNL) model, which estimated the influence of collaborative platform presence on categorical outcomes related to governance practices. Responses were categorised into ordinal and nominal scales, then dummy-coded to facilitate regression analysis. Model parameters were estimated using maximum likelihood estimation, allowing the authors to assess the relative effects of governance design choices on various dimensions of collaboration in smart city contexts.

Article **IV** examined the relationships between manufacturing digitalisation, dynamic capabilities, and technological innovation. The study focused on Chinese manufacturing firms actively engaged in digital transformation, particularly those located in pilot cities designated by China's Ministry of Industry and Information Technology. A stratified sampling strategy was used to ensure representation across firm ownership types, including state-owned, private, and foreign or joint ventures. The final sample consisted of 276 valid responses from mid- to senior-level managers. The questionnaire was developed through a multi-step process that involved literature review, expert validation, and back-translation to ensure construct reliability and conceptual clarity. The study used structural equation modelling to test the relationships among control variables (firm age, size, and ownership), the independent variable (manufacturing digitalisation), the potentially mediating variable (dynamic capabilities), and the dependent variable (technological innovation). Additional procedures were employed to test for non-response bias and confirmatory factor analysis, confirming the robustness and fit of the survey data and its suitability for hypothesis testing.

The individual original works constituting this thesis were presented on various occasions. The author was invited to present his research at the Institute of Economics, University of Freiburg, Germany. The author of this thesis also attended the World Urban Forum 2022, hosted by the United Nations Habitat Programme in Katowice, Poland. Furthermore, the author participated in and presented several manuscripts at the Smart Cities in Smart Regions Conference 2024 in Lahti, Finland, and the European Regional Conference of the International Telecommunications Society 2025 in Edinburgh, United Kingdom. In addition, the author of this thesis attended three editions of the summer schools organised by the Network for Public Administration Capabilities for Digital and

Sustainable Transition (PADST), held in Vihula, Estonia; London, United Kingdom; and Leuven, Belgium, where he also presented various manuscripts featured in this thesis. These opportunities provided valuable feedback and insights, contributing to the improvement of the manuscripts both individually and collectively. Moreover, the author of this thesis was member of a research team that principally carried out investigations in the framework of the projects Digital Governance in Cities (Reference CFP/2-2022-DGF) and Exploratory Study of Governance Models for Smart Cities for the United Nations (United Nations Human Settlements Program) and CAF – Development Bank of Latin America. Lastly, at the time of writing, in addition to the author's principal position at Tallinn University of Technology and its FinEst Centre for Smart Cities, the author was a visiting researcher at the Urban Innovation Policy Lab of Edinburgh Napier University.

Despite their rigour and variety, the methodological approaches employed in this thesis expose distinct limitations. First, two of the studies (Articles III and IV) rely primarily on survey data, which reflects individual perceptions and may be subject to personal biases. These limitations need to be taken into account given the complex nature of smart city governance, where respondents' interpretations of institutional arrangements or platform design may vary. To mitigate these risks, both surveys underwent rigorous validation procedures, including expert reviews, piloting, and translation protocols to enhance clarity and reliability across diverse settings. Additionally, the considerable sample sizes of responses (289 in Article III and 276 in Article IV) promise to partially mitigate personal biases. Second, while Article I systematically synthesizes the empirical literature on justice in smart cities and smart city governance, it is limited by the scope and framing of existing studies. Although PRISMA guidelines were followed to ensure methodological rigour, the findings are shaped by how justice-related concerns have been studied and reported in the academic literature to date. Third, Article II is conceptual in nature and does not draw on empirical data. While this format is well-suited for generating new theoretical perspectives and critiquing existing frameworks, its contributions ought to be further investigated.

The pluralistic methodological approach adopted in this dissertation was deliberately chosen to reflect an understanding of smart city governance as a multi-dimensional process that involves normative questions of justice, conceptual ambiguities, institutional design choices, and practices among public and private actors. No single method would be sufficient to capture these dimensions in isolation. The systematic literature review provides a necessary foundation by mapping how governance and justice have been addressed in existing empirical research. The conceptual analysis enables critical engagement with said research and supports theory development by drawing on insights from innovation management, which is central to the dissertation's cross-disciplinary ambition. The quantitative empirical studies, in turn, allow the dissertation to examine how governance arrangements and organisational capabilities operate in practice across a large number of cases.

At the same time, combining different methodological approaches may come along with challenges related to coherence, integration, and balance. For instance, the methods operate at different levels of analysis. Ensuring that each article's insights 'speak to one another,' rather than remaining fragmented, requires systematic integration, a clear analytical framework, and consistent anchoring in this dissertation's objectives. There is also a risk that methodological breadth may come at the expense of depth. This dissertation addresses this risk by explicitly positioning each article and their insights

within a coherent governance framework (see Sections 2.2 and 2.3) and by using synthesis to connect findings across methods. In doing so, the combined methodological approach strengthens the overall contribution of the dissertation, allowing it to capture the complexity of smart city governance while maintaining analytical coherence and alignment with its objectives.

4. Main Findings

This section presents the main findings of the four articles included in this thesis in relation to two of the four objectives set out in Table 1.

4.1. Identifying Smart City Governance Challenges

This sub section addresses Objective A: "Understand the smart city governance challenges." In doing so, it seeks to reflect on the issues that one can observe in relation to smart city governance in both theoretical discussions and practical applications.

Investigating theoretical discussions surrounding smart city governance, **Article II** identifies five major challenges that require stronger reasoning rooted in literature which, in turn, can inform practitioners: conceptualisation, strategy, monitoring, intermediation, and multilevel governance.

The first of these challenges highlights the need for a clearer and more inclusive conceptualisation of the smart city term. This need stems from three interrelated critiques. First, the term suffers from "terminological confusion" (Dameri & Cocchia, 2013, p. 5), with scholars and practitioners employing labels such as sustainable, digital, intelligent, or green interchangeably, despite their distinct meanings. This lack of consensus has led to misinterpretations that cast doubt on the effectiveness of the smart city concept itself. Second, the term is overly city-centric, neglecting the fact that smart city projects are often implemented at regional, neighbourhood, or even infrastructural levels, as highlighted in the discussion on collaborative governance arrangements of Section 2.2 of this thesis. Third, many definitions frame smart city development as a one-size-fits-all application of technological solutions, rather than as context-dependent transformations in which technologies are embedded in social structures. Such technologically deterministic views have been critiqued for serving technology providers' interests and accelerating power imbalances between collaborating partners, as highlighted in Section 2.1 of this thesis (**Article II**).

In relation to the second challenge identified in **Article II**, the author of this thesis argues that the strategic coordination of smart city initiatives remains underexplored. Although scholars stress the need for digital innovation strategies that can orchestrate diverse actors, their resources, and the projects that they initiate, little guidance exists on how to design comprehensive and adaptable frameworks tailored to local contexts. As a result, practice often advances faster than theory, while many strategies remain overly abstract or narrowly focused on technology, neglecting social and environmental dimensions.

Moreover, a line of argumentation is presented in **Article II** that shows that research on the monitoring of smart city projects, including their status of implementation and achievement of defined goals, is still limited. Existing monitoring tools tend to prioritise ranking cities by their level of 'smartness' rather than evaluating the actual quality and innovation of projects, their underlying processes and effective outcomes. Current approaches also tend to rely on static indicators that fail to capture ongoing performance, lack clear guidelines for measurement, and struggle to integrate diverse data sources. As a result, practitioners often face challenges in finding adaptive tools that can combine multiple forms of data while responding to the specific conditions of local contexts.

Fourth, as argued throughout Section 2 of this thesis, smart city projects are collaborative by nature, involving diverse actors and complex networks. Intermediary

organisations, such as collaborative platforms (see Sections 2.2, 2.3 and 4.2) are expected to help coordinate efforts and foster innovation networks. However, questions persist about their authority, organisational structures, integration into governance, and resource demands in the context of smart city development (**Article II**).

Fifth, **Article II** echoes discussions presented in Section 2.3 of this thesis, and shows that while multilevel governance is often presented as an enabler of collaboration in smart city projects, it can also produce challenges. For instance, national strategies and funding schemes can impose priorities that overlook or even contradict local needs, creating tensions between levels of authority. Similarly, fragmented responsibilities across government tiers may lead to duplication, competition, or gaps in implementation. Horizontal coordination may also prove to be difficult, as sustainability challenges frequently extend beyond municipal borders and require cooperation between neighbouring jurisdictions, which is often hindered by competing interests or uneven resource distributions.

Which implications do these challenges that are rooted in theoretical gaps and expressed in deficient practical implementations of smart city projects have in terms of justice and inclusivity for citizens? By means of a systematic literature review, **Article I** addresses this concern and investigates notions of (in-) justice experienced by citizens in smart city development. Based on this review, in Article I, the author of this thesis argues that smart city projects tend to risk deepening inequalities by neglecting the needs of citizens and vulnerable groups in particular, positioning justice and inclusion as central concerns. Low-income communities are particularly affected, often excluded from decision-making processes and disproportionately impacted by the digital divide, limited skills, and poor access to affordable services such as housing and transport. Ethnic minorities face barriers in employment and digital connectivity, while also being subject to discriminatory practices like surveillance that undermine their rights. Elderly populations tend to experience mobility challenges and difficulties adapting to digital technologies, which can leave them isolated from accessing urban services. Women's needs are often overlooked, with issues such as safety in public spaces and underrepresentation in policymaking limiting their influence on smart city trajectories. Similarly, physically challenged individuals face inadequate infrastructure and accessibility while assistive technologies introduce privacy concerns. Children, too, have crystallised as being vulnerable in the review conducted for Article I, especially when educational or environmental dimensions are neglected. Moreover, certain occupational groups and their needs for being able to carry out their occupations in urban spaces remain excluded from urban planning considerations. These patterns highlight overlapping injustices across distributional, recognitional, and infrastructural dimensions, showing that the benefits of smart city projects tend to be unevenly distributed, and adverse effects disproportionately assumed by vulnerable segments of the population. Ethical concerns further solidify this impression, urging calls for greater transparency, inclusive participation, and equitable access to resources. While awareness of these issues is increasing, citizen engagement and the inclusion of marginalised groups remain insufficient, signalling an urgent need to integrate justice more systematically into smart city governance.

Article I further revealed that justice concerns in smart city development may vary across regions but consistently expose structural inequalities and gaps in inclusion. In the Americas, justice debates largely centre on governance and mobility, where public-private partnerships and gentrification tend to prioritise efficiency and private

interests at the expense of low-income groups. Procedural justice is a recurring theme, as marginalised communities are excluded from shaping policies and mobility solutions that affect their daily lives. Europe's smart city discourse tends to focus on procedural and recognitional justice, particularly around citizen participation and data governance. While inclusive rhetoric is common, participation often remains symbolic, and mobility systems continue to neglect groups such as the elderly and people with disabilities. In Asia, governance and mobility are joined by environmental justice as central concerns. Gender-sensitive initiatives and assistive technologies highlight progress, yet surveillance and environmental degradation expose how already marginalised groups often bear disproportionate adverse effects. Africa's discourse on justice in smart city development is less pronounced, with justice issues typically described in broad terms. Yet, persistent inequalities in access to water, energy, and digital infrastructure point to distributional and procedural challenges that remain understudied. Oceania, meanwhile, has only a limited presence in the debate, though Indigenous rights and ecological concerns are beginning to shape discussions. Taken together, these findings show how justice in smart cities extends far beyond technology, raising fundamental questions about equity, participation, and whose interests are prioritised in urban development, thereby echoing concerns raised in Section 2 of this thesis.

4.2. Exploring Approaches towards Smart City Governance

This section explores how different approaches to smart city governance may or may not respond to the challenges outlined in Section 4.1 of this thesis. In doing so, it seeks to highlight both potential strengths and weaknesses of different governance approaches, and generate insights that ultimately inform the design of more effective governance arrangements.

4.2.1. Collaboration for Smart Cities

As argued throughout this thesis, collaboration among diverse stakeholder groups is a cornerstone of governing smart city projects. The findings of **Article I** reinforce this point. Through a systematic literature review on justice in smart cities, the author of this thesis demonstrates that the ways in which collaborations are implemented in practice are both crucial and contested. Indeed, among the 67 reviewed articles, procedural justice emerged as the most common theme, with 27 studies stressing the importance of inclusive and participatory decision-making, while highlighting challenges that oftentimes emerge in practice. Distributional justice was also widely discussed in 25 articles, drawing attention to the unequal allocation of resources across different demographic groups. Recognitional justice appeared in 11 studies, underscoring the neglect of underrepresented communities within smart city policies. Restorative justice was examined least often, with only three studies focusing on mechanisms of reconciliation in contexts marked by conflict or inequality.

Moreover, **Article I** also revealed ethical considerations that shape the debate on inclusion and fairness in collaborations for smart city development. Public participation and inclusive governance were identified as major ethical concerns in 21 studies. The digital divide was noted in twelve articles, drawing attention to its disproportionate impact on marginalised communities. Issues of inequitable access to resources were highlighted in eight studies, while privacy concerns were raised in four, particularly with regard to physically challenged individuals relying on assistive technologies. Further

discussions centred on transparency, cultural and social impacts, and environmental ethics, each noted in five studies, illustrating the complex notions of ethics which smart city projects need to navigate.

4.2.2. Collaborative Platforms for Smart Cities

According to various theoretical debates (see Sections 2.2 and 2.3), collaborative platforms managed by municipal governments can help structure and coordinate collaborations both within and across projects for smart city development. Based on a review of the literature on collaborative platforms, the author of this thesis identifies eight governance arrangements that these platforms are assumed to support in existing theoretical discussions. Using these arrangements as hypotheses, **Article III** then examines the extent to which collaborative platforms are likely to facilitate them by means of a multinominal logit model based on global survey that comprises nearly 300 responses from city representatives worldwide. In the following, each hypothesis derived from collaborative platform theory and the corresponding analysis based on empirically grounded survey data are presented.

H1: Collaborative platforms increase the likelihood of municipal governments engaging in knowledge-sharing activities with other societal actors.

The results provide support for Hypothesis 1. Municipalities with a collaborative platform are more likely to engage in knowledge-sharing activities related to smart city development compared to those not engaged in any knowledge-sharing activities. Specifically, they are about five times more likely to participate in at least one form of knowledge exchange, eleven times more likely to engage in two forms, and thirty-seven times more likely to be involved in all three forms of knowledge-sharing that respondents were presented with: (1) exchanging knowledge within the city with actors such as public agencies, universities, local firms, and residents; (2) sharing knowledge through national-level networks, initiatives, or programmes, including fora, working groups, and collaboration schemes; (3) engaging in international knowledge-sharing via transnational projects, alliances, and platforms such as those supported by the EU or global city networks. These findings show that collaborative platforms not only increase the likelihood of participation compared to municipalities without such engagement, but also broaden the scope of knowledge-sharing, potentially embedding municipalities more deeply in local, national, and international networks that are critical for advancing smart city development.

H2: Collaborative platforms increase the likelihood of municipal governments developing a culture supportive of innovation.

The analysis of H2 introduces a degree of ambiguity. The results show that collaborative platforms can play a role in fostering an innovation-oriented culture within municipal administrations. Municipalities with a collaborative platform are about five times more likely to agree that they encourage experimentation, openness to new ideas, risk-taking, and learning from failure compared to those in the neutral category (neither disagree nor agree). Moreover, these municipalities are less likely to disagree with such statements, being only 0.38 times as likely to fall into the Disagree category relative to the neutral base. At the same time, however, also municipalities without a collaborative platform demonstrate some tendency towards innovation-supportive practices, being nearly three times more likely to agree compared to the neutral baseline. Overall, the findings suggest that while collaborative platforms may strengthen the likelihood of

local administrations adopting innovation-supportive practices, such practices can also emerge in municipalities without a collaborative platform, though to a more limited extent.

H3: Collaborative platforms increase the likelihood of municipal governments developing the leadership, managerial, and technical competences required to manage collaborative governance initiatives.

The analysis of H3 indicates continued ambiguity. The results show a positive relationship between collaborative platforms and the development of leadership, managerial, and technical competencies needed for smart city coordination. Municipalities with a collaborative platform are about twice as likely to agree that they have the necessary competencies compared to those who neither disagree nor agree (i.e. the neutral category), and they are significantly less likely to disagree, being only about a third as likely to report a lack of competencies relative to the neutral baseline. Interestingly, municipalities without a collaborative platform also show some positive association with the Agree category, being roughly 1.8 times more likely than neutral respondents to claim they possess such competencies, though this effect is weaker than in municipalities with a collaborative platform. Overall, the results suggest that while competencies can develop without collaborative platforms, their presence is more strongly associated with higher perceived coordination capacity, indicating that collaborative platforms may support fostering these capabilities.

H4: Collaborative platforms increase the likelihood of municipal governments having an institutionally endorsed strategy that integrates multiple collaborative initiatives and aligns stakeholders around shared objectives.

The results for H4 are less ambiguous; They indicate that collaborative platforms are positively linked to the adoption of formal strategies for smart city development. Municipalities with a collaborative platform are around 1.5 times more likely to have an officially adopted strategy, such as a roadmap or strategic plan, compared to those without. Conversely, municipalities lacking a collaborative platform are less likely to report having such a strategy in place, highlighting a negative association. These findings suggest that the presence of a collaborative platform increases the likelihood that municipal governments formalise their efforts through strategic orientation, thereby aligning stakeholders around shared objectives.

H5: Collaborative platforms increase the likelihood of municipal governments monitoring the collective progress and outcomes of collaborative governance initiatives.

The analysis of H5 reveals no evidence that collaborative platforms increase the likelihood of municipalities adopting monitoring systems for smart city projects. While municipalities without a collaborative platform are about 72% less likely to have such systems in place compared to the base category, the presence of a collaborative platform shows no statistically significant effect. These findings suggest that although the lack of a collaborative platform is linked to weaker monitoring capacity, collaborative platforms themselves do not appear to drive the adoption of monitoring practices. Instead, other institutional or contextual conditions may be more influential in determining whether municipalities establish systems to track progress and outcomes.

H6: Collaborative platforms increase the likelihood of vertical coordination between municipal and higher levels of government.

The results of H6 reflect that collaborative platforms are linked to improved vertical coordination, though not exclusively. Municipalities with a collaborative platform are

about 38% less likely to report poor coordination with higher-level governments compared to the neutral baseline (neither disagree nor agree), and around 1.7 times more likely to report effective coordination instead. However, municipalities without a collaborative platform show a similar 1.7-fold increase in reporting effective coordination. Hence, these results provide only partial support for H6, as they suggest that while collaborative platforms may contribute to improved vertical coordination, other institutional or contextual factors appear to play an equally important role.

H7: Collaborative platforms increase the likelihood of achieving coordination across departments and agencies within the municipal government.

When examining H7, the findings reveal that collaborative platforms are positively associated with higher levels of effective internal coordination across municipal departments, units, and agencies. Municipalities with a collaborative platform are about five times more likely to agree that coordination is effective compared to those in the neutral category (neither disagree nor agree), while those without a collaborative platform are still twice as likely to agree relative to the same baseline. Both groups also show a lower probability of reporting poor coordination, with municipalities with a collaborative platform being 52% less likely and those without a collaborative platform 58% less likely to disagree. These results support H7 by showing that collaborative platforms strengthen internal collaboration, although the presence of effective coordination is not entirely contingent on them.

H8: Collaborative platforms increase the likelihood of municipal governments retaining decision-making power when collaborating with private actors.

For H8, the analysis highlights a complex and arguably the most ambiguous picture among all hypotheses tested in Article III. Municipalities with a collaborative platform are about 11 times more likely to report strong decision-making authority compared to those who neither disagree nor agree (i.e. the neutral category). However, municipalities without a collaborative platform are even more likely, around 13 times, to report retaining such authority relative to the same baseline. These findings suggest that while collaborative platforms can support municipal decision-making power in public-private collaborations, they are not the only mechanism for doing so. In fact, other governance arrangements may be equally or even more effective, calling into question whether collaborative platforms are essential for safeguarding municipal authority in decision-making.

In sum, the findings reveal a mixed picture. Clear support emerges for only two hypotheses: collaborative platforms are strongly linked to a greater likelihood of engaging in knowledge-sharing across different levels (H1) and to adopting formal strategies that align stakeholders and initiatives (H4). Monitoring capacity, however, shows no such link, as the presence of collaborative platforms does not increase the likelihood of municipalities implementing monitoring systems (H5). For the remaining hypotheses (H2, H3, H6, H7, H8), collaborative platforms are positively associated with the various collaborative governance arrangements, but municipalities without collaborative platforms often demonstrate similar or even stronger outcomes. The results for H6 (vertical coordination) and H8 (decision-making power in public-private partnerships) are especially ambiguous, as municipalities without collaborative platforms appear just as likely, if not more likely, to perform well in these dimensions. Overall, collaborative platforms seem to play a supportive but not necessarily essential role, with their contribution to collaborative governance contingent on specific contexts rather than universal across all dimensions.

4.2.3. Dynamic Capabilities for Smart Cities

Lastly, **Article IV** investigates the importance of dynamic capabilities for smart city development. Building on the theoretical discussion presented in Section 2.2, this section investigates the role of dynamic capabilities as a mediating factor between manufacturing digitalisation on one hand, and technological innovation, captured through product and process innovation, on the other. In particular, Article IV uses survey data from 276 manufacturing firms located in the first national-level pilot cities for digital transformation in China, and employs a structural equation modelling approach to investigate this hypothesised connection.

The empirical findings show a clear positive correlation between manufacturing digitalisation and technological innovation. Firms that proactively adopt digital practices achieve stronger innovation outcomes, with process innovation benefiting the most ($\beta = 0.498$, $p < 0.001$) and product innovation showing a weaker, though still positive, effect ($\beta = 0.176$, $p < 0.01$). The results indicate that digitalisation enhances design flexibility, shortens development cycles, and improves alignment with market demands, thereby strengthening both process and product innovation.

Moreover, the results of Article IV suggest that dynamic capabilities play a mediating role between manufacturing digitalisation and technological innovation. They show that digitalisation strengthens innovation outcomes when firms can sense, seize, and reconfigure resources effectively, with dynamic capabilities shaping both product and process innovation in distinct ways. In line with this, digitalisation was found to have a significant positive effect on dynamic capabilities, which in turn are strongly associated with both product innovation and process innovation. This highlights that the innovation benefits of digitalisation depend not only on technology adoption but also on the presence of strong organisational capacities to adapt and respond. In particular, the data show that dynamic capabilities partially mediate the link between manufacturing digitalisation and process innovation. While the direct effect of digitalisation on process innovation remains significant, its strength is reduced once dynamic capabilities are accounted for.

The analysis further suggests that dynamic capabilities act as a full mediator between manufacturing digitalisation and product innovation. When the mediator is included, the direct effect of digitalisation on product innovation becomes non-significant, indicating that innovation benefits are realised only when firms actively develop their ability to reconfigure resources and adjust organisational structures. Digital technologies such as 3D printing, the Industrial Internet of Things, or artificial intelligence may offer innovation potential, but without effective dynamic capabilities firms risk failing to capture their full value.

To summarise, the structural equation modelling results yielded by **Article IV** reveal that, firstly, advancing digitalisation within manufacturing firms is likely to boost technological innovation, with stronger effects observed for process innovation than for product innovation. Secondly, these innovation outcomes are not solely the result of direct digitalisation effects; dynamic capabilities play a pivotal mediating role. In particular, they partially mediate the link between digitalisation and process innovation, while fully mediating the relationship between digitalisation and product innovation.

5. Discussion

The findings of this thesis support the assertion that "policies have a critical role to play in fostering smart cities [and] that solving societal problems is not merely a question of developing good policies but much more a managerial question of organising strong collaboration between government and other stakeholders" (Meijer & Bolívar, 2015, p. 394). For instance, the results of **Article IV** demonstrate the mediating role of dynamic capabilities between manufacturing digitalisation and technological innovation, expressed through product and process innovation. This in turn highlights the importance of conducive governance mechanisms. Similarly, the analysis in the context of the systematic literature review in **Article I** identified Governance and Administration as the most frequently cited sectoral focus, with 21 of the 67 reviewed articles referring to it. However, this thesis also highlights issues with governance arrangements for smart cities and underlying collaborations. For instance, among the 67 reviewed articles for **Article I**, procedural justice emerged as the most common theme, with 27 studies stressing the importance of inclusive and participatory decision-making, while highlighting challenges that oftentimes emerge in practice.

5.1. Cross-Disciplinary Perspective: Contributing to Strengthening the Theoretical Foundations of Smart City Governance

How can the theoretical development of the field of smart city governance be sustained and accelerated in the future on the basis of this thesis? This section aims to address this question and outlines pathways for strengthening and advancing the theoretical foundations of smart city governance, particularly by drawing on and highlighting the potential contributions of theoretical concepts from the adjacent fields of innovation management studies and collaborative governance. In doing so, this section delves on **Objective C** of this thesis: Contribute to strengthening theoretical foundations for smart city governance by means of a cross-disciplinary approach.

5.1.1. Smart City Governance and Innovation Management Studies

In addition to highlighting persistent issues and resulting challenges in our theoretical understanding of smart city governance (see Section 4.1), **Article II** also presents concepts stemming from innovation management studies that might help overcome these challenges and inform the study of smart city governance.

In relation to the conceptualisation challenge, innovation management studies can provide insights by reframing this challenge through the lenses of sensehiding and sensemaking. As outlined in Section 4.1 of this thesis, the persistent ambiguity surrounding what the smart city term entails has often led scholars and practitioners to selectively emphasise aspects of the concept that align with their own objectives while ignoring others. Innovation theory highlights that such selective framing resembles a form of sensehiding. To address this, the concept of sensemaking offers a more constructive approach, aiming to support shared interpretations through iterative negotiation and alignment across diverse actors. In practice, this means treating the very conceptualisation of the smart city term as a boundary object, flexible enough to accommodate varied, context-dependent perspectives yet sufficiently robust to sustain a commonly accepted definition (see Hübel, 2022; Mäenpää et al., 2016; Pizzo et al., 2021).

As noted in Section 4.1 in the context of the strategy challenge, traditional approaches to urban strategy are often too rigid or narrowly focused on technological or infrastructural aspects, overlooking the dynamic, long-term orientation that digital innovation demands. Technology strategy and transition studies, particularly those drawing on technology roadmapping, offer useful tools for addressing this gap. Roadmapping approaches emphasise strategic alignment, mid- to long-term planning, and the capacity to adapt to shifting technological landscapes, thereby helping cities manage the full life cycle of technologies while linking technical components to wider socio-technical demands (see Lee et al., 2011; Martin & Daim, 2012; Phaal et al., 2004). In addition, insights from open strategy highlight the importance of flexibility, inclusiveness and bottom-up contributions in strategy design, recognising that smart city projects must evolve in response to new opportunities, citizen input and emerging trends (see Chesbrough & Appleyard, 2007; Hautz et al., 2017). By drawing on both roadmapping and open strategy theories, innovation management studies can provide smart city governance with methods to develop adaptable, inclusive and future-oriented strategies.

The development of innovation indicators, for instance, allows monitoring (3rd challenge mentioned in Section 4.1) to extend beyond narrow approaches to measuring the outputs of smart city projects by incorporating both product- and process-oriented dimensions, from early-stage idea generation to post-implementation outcomes. This widens the scope of evaluation to include not only technical and financial performance but also intangible aspects such as learning and capacity building (see Dziallas & Blind, 2019; Truffer et al., 2017). Moreover, the concept of developmental evaluation provides a framework believed to be better suited to the complexity of smart city projects. By embedding participatory monitoring into the project process, developmental evaluation treats stakeholders not only as informants but as co-creators of the monitoring system, enhancing reflexivity, learning, and adaptability. This approach is particularly valuable in the volatile context of digital innovation, where expectations, technologies, and governance demands may change rapidly (see Lam & Shulha, 2015; Patton, 2016).

In the context of the intermediation challenge persistent in smart city governance research, innovation studies suggest the concept of innovation intermediaries, which represent a pendant to collaborative platforms rooted in collaborative governance literature (see Section 2.2, 2.3 and 4.2). Innovation studies show that intermediaries operate not only as brokers between actors but also as systemic intermediaries capable of shaping entire innovation ecosystems. This is particularly relevant for municipal organisations, which must enable collaboration in smart city projects while also coordinating citywide strategies (see Howells, 2006; Kanda et al., 2020; Rossi et al., 2022; Sovacool et al., 2020; van Lente et al., 2003). Yet, questions about the scalability of dedicated innovation intermediaries for smart city development are yet to be addressed, especially in smaller urban areas with limited resources, where transformational leadership through certain individuals or groups may substitute for dedicated and oftentimes resource-intensive organisations (see Aarons & Sommerfeld, 2012; Paulsen et al., 2009).

Lastly, innovation management studies can offer valuable insights for addressing issues emerging in the context of multilevel governance. Boundary management theory, for example, highlights how institutional settings positioned at different administrative levels intersect in “boundary zones,” where regulatory frameworks and organisational

resources must coexist. Analysing these zones can uncover not only where tensions arise but also where better coordination might be possible (see Capurro et al., 2021; Garzella et al., 2021; He & Berry, 2022). Complementary perspectives from the literature on scaling innovation add another dimension by showing how innovations travel across levels: through up-scaling to higher authorities, out-scaling across networks, or down-scaling into local contexts (see de Roo et al., 2019; Schut et al., 2020). Together, these approaches can help explain how local experimentation may shape broader policies, how supra-local directives influence municipal practices, and how more effective inter-level coordination might be designed for smart city governance.

5.1.2. Smart City Governance and Collaborative Governance

In addition to the perspectives provided by innovation management studies, collaborative governance theory may offer conceptual stimuli for strengthening the theoretical apparatus of smart city governance. **Article III** of this thesis illustrates this potential: Collaborative governance emphasises inclusive decision-making, joint accountability, and the pooling of diverse resources (Ansell & Gash, 2008). These elements are particularly relevant to the smart city context, where projects typically involve a multiplicity of stakeholders from public, private, academic, and civic domains.

The empirical findings of **Article III** show that collaborative governance theory provides a useful lens for analysing both the promises and limitations of collaborative platforms in the context of smart cities. For example, the results indicate that platforms are consistently associated with stronger knowledge-sharing practices and the adoption of formal strategies, two core dimensions of collaborative governance capacity. At the same time, the findings reveal the contingent nature of collaborative platforms. In areas such as innovation culture, competence development, vertical and internal coordination, and decision-making power, platforms are linked to positive outcomes but not in a decisive or uniform manner. Municipalities without platforms often report similar or even stronger capacities, underscoring that platforms are not a panacea.

Collaborative governance theory can thereby help deepen our understanding of smart city governance by shifting focus from technological outputs to the relational and institutional dynamics of collaboration in smart cities (see Ansell & Gash, 2018; Emerson & Nabatchi, 2015). It highlights the importance of examining not only whether collaboration occurs, but how it is structured, whose interests it serves, and under what conditions it leads to potentially sustainable and equitable outcomes (see Florini & Pauli, 2018). By bringing these concerns into the study of smart city governance, collaborative governance theory can help build a more robust, context-sensitive, and critically informed foundation for addressing the challenges of governing smart cities.

5.2. Towards Core Principles of Smart City Governance

In light of the empirical findings of this thesis and the accompanying theoretical discussions, how can core principles be formulated to complement contemporary theories and practices of smart city governance? This section sets out the key principles of smart city governance that have crystallised in the course of this research. In doing so, it addresses **Objective D** of this thesis: Formulate key principles of smart city governance.

5.2.1. Sociotechnical

A growing, though still relatively limited, body of literature argues for moving beyond techno-centric definitions of the smart city, framing it instead as the co-evolution of elements such as technologies and infrastructure, with factors including societal needs and justice (see Section 2.1). Yet, smart city governance approaches that promise to achieve this combination of these elements and factors in smart city development are scarce (see Sections 2.3 and 4.2).

As argued in **Article II** of this thesis, a sociotechnical interpretation of the smart city concept and corresponding approach to governing smart cities may not only help broaden the scope of smart city development beyond purely technological narratives but also situates it within dynamic processes of inclusive innovation as well as adaptation and institutional change. In doing so, innovation management perspectives can help provide a pathway for developing clearer, more inclusive and actionable conceptualisations of smart city governance.

5.2.2. Inclusive

Echoing the theoretical discussions in the literature on collaborative governance (see Section 2.2), the findings of this thesis further highlight the issue of power imbalances in collaborations within the empirical context of smart city development. **Article II** raises the issue of technocentric definitions of the smart city term persistently being dominant, thereby potentially giving rise to the interests of private technology providers. **Article I** further reflects the issue of power imbalances by showing how less influential communities and their interests are especially affected and sidelined by smart city developments, as they are often excluded from decision-making and disproportionately burdened by the digital divide, limited skills, or restricted access to essential services. These patterns underscore overlapping injustices across distributional, recognitional, and infrastructural dimensions, revealing how the benefits of smart city projects are unevenly distributed while vulnerable groups shoulder most of the adverse effects. **Article III** further underscores concerns regarding decision-making power by suggesting that collaborative platforms may fall short in addressing power asymmetries within public-private partnerships. Instead, collaborative platforms risk unintentionally enabling more powerful actors to advance self-serving goals under the guise of collaborative governance.

The author of this thesis thereby complements smart city governance literature that sketches various issues that many cities face in coordinating government, industry, academia, and citizens within collaborative governance arrangements for smart city development (see Vallance et al., 2020). For instance, scholars such as Nguyen et al. (2022) frame smart city collaborative ecosystems as configurations that bring together quadruple helix actors, each drawing on distinct sources of power and influence. Indeed, in smart city projects, power relations among partners have been portrayed as oftentimes being unbalanced. Particularly the role of private vendors of ICTs and the resulting dependence on their installation, utilisation, and maintenance can create power imbalances and lead to private interests being prioritised (Alizadeh & Sharifi, 2023). Such asymmetries risk disproportionately affecting vulnerable groups (Haque & Sharifi, 2024b). If their specific needs, capacities, and perspectives are overlooked, these groups may become systematically excluded from the opportunities and benefits of smart city development and instead be exposed to adverse effects, thereby potentially

exacerbating existing socio-economic disparities (Kolotouchkina et al., 2024; Kolotouchkina et al., 2023; Rosales & Fernández-Ardèvol, 2020; Voorwinden & Ranchordas, 2021).

Building on the literature reviewed for **Article I**, the author of this thesis presents pathways that can guide more just and inclusive approaches to smart city governance. Central among these is the need for greater transparency and accountability, ensuring that projects are not shaped primarily by political rhetoric or market-driven priorities but remain aligned with residents' needs (see Diaz et al., 2021; Masucci et al., 2021). Equally important is the empowerment of vulnerable communities, recognising that technology alone does not guarantee fairness and that meaningful participation, digital literacy, and open access are essential to prevent existing divides from widening (see Asteria et al., 2020; Tupasela et al., 2023). Building on this, technology must be used to improve accessibility, with safeguards to guarantee that citizen voices and data rights are respected, while avoiding practices that reinforce exclusion or create new inequalities (see Carter, 2013; Goodman & Powles, 2019). Governance arrangements for smart cities must also address the socio-economic barriers that limit who benefits from innovation, by ensuring that opportunities reach marginalised groups and by creating pathways for residents themselves to contribute solutions rooted in their lived experiences (see Aminah, 2021; Lung-Amam et al., 2021). Finally, attention to history and legacy is vital, as past injustices can continue to shape current urban realities. Instead, future-ready smart city development requires recognising and addressing these embedded inequities so that digital transformation serves all urban communities (see Lahat & Nathansohn, 2023; Snis et al., 2021). Taken together, these pathways promise to provide a framework for aligning smart city projects with broader goals of inclusivity.

5.2.3. Temporal

The third guiding principle that has crystallised in this thesis is represented by the element of temporality in smart cities and corresponding approaches to governance. **Article I**, for instance, highlights that justice should be embedded from the outset as a foundational principle in the governance of smart city initiatives, thereby positioning justice not as a fixed outcome but as an ongoing, adaptive, and temporal process that informs and guides decisions throughout all phases of urban development. **Article II** follows a similar reasoning and argues that the smart city term itself is temporal and subject to need-, context- and time-dependent adjustments and reconsiderations, thereby requiring sensemaking. In this perspective, sensemaking provides a collaborative process through which diverse actors can align their interpretations, draw on past experiences, and establish a more coherent and evidence-driven understanding of the smart city concept, reducing both conceptual and practical ambiguities. Moreover, the results of **Article IV** show that dynamic capabilities that are responsive to changing contextual conditions and needs over time are conducive to technological product and process innovation.

The element of temporality has also been highlighted in theoretical discussions surrounding smart cities. As presented in Section 2.1 of this thesis, the term smart should not be understood as a binary condition of "being smart" or "not being smart," but as a continuum where local governments, citizens, private actors, and academics engage in initiatives that gradually improve urban life. Approaches to governing smart cities thereby necessarily have to account for their inherently temporal and fast-changing dynamics. This includes addressing the politics of using real-time technologies in urban

management and daily life, while also considering the integration of differently paced rhythms of urban systems and stakeholders, thereby adopting an ethics that accepts temporal differences (Kitchin, 2018).

Article IV suggests dynamic capabilities as a potential tool of dealing with the temporality of smart cities. As outlined in Section 4.2 of this thesis, dynamic capabilities can help an organisation innovate and adapt on an ongoing basis, reshape processes, develop new services, and adjust product delivery in response to changing circumstances. Hence, the author of this thesis positions dynamic capabilities as a crucial element of governing temporality in smart cities, linking to scholars such as Kattel et al. (2025) who emphasise the importance of dynamic capabilities such as (i) cultivating strategic awareness, (ii) adapting city development priorities, (iii) building adaptive coalitions, (iv) transforming resources, and (v) embedding experimentation for resilient urban management.

6. Conclusion

This thesis seeks to address four objectives. First, it aims to "understand the smart city governance challenges" (**Objective A**). The results of this thesis highlight five interconnected challenges that shape smart city governance: conceptualisation, strategy, monitoring, intermediation, and multilevel governance. Ambiguities in defining the smart city concept, limited guidance on strategic coordination, and inadequate monitoring tools illustrate gaps between theory and practice. At the same time, questions about the authority and capacity of intermediary organisations, together with tensions between different levels of government, reveal structural weaknesses in contemporary governance arrangements. These challenges have important implications for justice and inclusion. Smart city projects often risk deepening inequalities by excluding vulnerable groups such as low-income communities, ethnic minorities, elderly populations, women, children, and people with disabilities. Across regions, patterns of distributional, procedural, and recognitional injustice emerge, showing that while the rhetoric of smart city development often stresses innovation and efficiency, its practical implementation tends to reproduce or even exacerbate existing socioeconomic divides.

Second, this thesis seeks to "explore how different approaches to smart city governance can help address societal needs, manage collaboration, and navigate fast-changing environments in order to inform more effective governance design" (**Objective B**). The results show, first, that collaboration is indispensable yet contested in smart cities, with participatory processes being shaped by persistent ethical concerns around digital divides, privacy, and unequal access. Second, municipal collaborative platforms can help, most clearly by increasing knowledge sharing and the adoption of formal strategies, but their effects on innovation culture, competence building, vertical and internal coordination, and public decision-making power are not necessarily decisive. Third, adaptive capacity matters, since findings on dynamic capabilities indicate that organisations better translate digital manufacturing tools into innovation when they can sense opportunities, mobilise resources, and reconfigure structures over time. Taken together, these insights point to governance designs that pair inclusive collaboration with intentional collaborative platform use and deliberate capacity building, so cities can align stakeholders, learn, and adjust in fast moving contexts.

Third, this thesis represents an effort to "contribute to strengthening theoretical foundations for smart city governance by means of a cross-disciplinary approach" (**Objective C**). In doing so, it demonstrates how perspectives from innovation management studies and collaborative governance theory can enrich and extend the field. From innovation management, concepts such as sensemaking, technology roadmapping, open strategy, innovation intermediaries, and boundary management provide tools for addressing persistent challenges of conceptualisation, strategy, monitoring, intermediation, and multilevel governance. From collaborative governance theory, the thesis shows that insights into inclusiveness, joint accountability, and power relations are essential for understanding the promises and limits of collaborative platforms and collaboration more generally in smart city contexts. Together, these contributions underline the value of cross-disciplinary approaches for developing a more comprehensive and critically informed theoretical foundation for smart city governance, one that integrates technological, institutional, and social perspectives.

Fourth, in an effort to "formulate key principles of smart city governance" (**Objective D**), this thesis identifies three guiding principles. First, smart city governance should be understood as sociotechnical, reflecting the co-evolution of technologies with social needs and institutions rather than treating smart cities as purely technological projects. This broadens governance approaches beyond technological determinism and anchors them in justice-oriented innovation. Second, inclusivity is essential. Findings show persistent power imbalances in smart city projects, with vulnerable groups often excluded or disadvantaged. Addressing this requires transparency, citizen participation, and technology and accompanying governance approaches that enhance accessibility, while also recognising and accounting for socio-economic and historical barriers that shape inequalities. Third, temporality is central. Justice and inclusion should be seen as ongoing processes, while the smart city itself and its manifestations must be treated as flexible and evolving. Dynamic capabilities can provide a useful framework in this respect, enabling stakeholders and actors to adapt, reconfigure resources, and respond to changing conditions.

6.1. Theoretical Contributions

The theoretical contributions of this thesis promise to advance the field of smart city governance in several ways. For instance, the thesis enriches the debate on conceptual clarity by linking smart city research with innovation management theory. Concepts such as sensemaking, technology roadmapping, and innovation intermediaries provide new tools for addressing persistent challenges of conceptualisation, strategy, monitoring, intermediation, and multilevel governance. This extends the often-voiced critique of fragmented and techno-centric approaches by offering alternative theoretical lenses that foreground adaptability, alignment, and context-sensitive strategies.

Moreover, the thesis strengthens the analytical foundation of collaboration in smart city research. By testing hypotheses on the role of collaborative platforms, it demonstrates both their potential and their limitations. These findings contribute to an emphasis on collaboration inherent to smart city development, showing that governance arrangements are contingent rather than universally effective.

Additionally, the thesis integrates dynamic capabilities theory into smart city governance debates. This thesis highlights the importance of adaptability in the face of fast-changing urban environments; Article IV operationalises this by showing how sensing, seizing, and reconfiguring resources mediate the link between digitalisation and innovation. This extends governance theory by including organisational learning and adaptive capacity as central to governing smart city projects.

Furthermore, this thesis positions justice as a foundational lens for understanding smart city governance. By systematically reviewing how different dimensions and types of justice are addressed or neglected in practice, the thesis demonstrates how smart city projects risk reproducing or deepening inequalities. This contribution anchors justice more firmly within smart city governance theory, highlighting equity, participation, and inclusivity as central concerns that must be integrated from the outset rather than treated as afterthoughts.

Lastly, referring to the core principles of smart city governance outlined in Section 5.2., the sociotechnical, inclusive, and temporal principles contribute to an agenda for future research on smart city governance. They invite scholars to move beyond technology-focused evaluations and instead examine how governance arrangements emerge from the interaction between technical systems, institutional structures, and

social value over time. In particular, the sociotechnical principle encourages research designs that integrate technological, organisational, and societal considerations, encouraging cross-disciplinary and mixed-method approaches. The inclusive principle calls for greater attention to power relations, notions of justice, and the experiences of marginalised groups and overlooked contexts. Finally, the *temporal* principle highlights the need for longitudinal and process-oriented studies that capture adaptation, learning, and institutional change across different phases of smart city development. Together, these principles provide a conceptual lens that may guide future research towards more context-sensitive and theoretically robust understandings of smart city governance.

6.2. Practical Contributions

In addition to theoretical contributions, this thesis offers several practical contributions for policymakers, municipal leaders, and practitioners engaged in smart city development. It highlights the importance of moving beyond technology-driven narratives, showing that effective governance must balance technological solutions with social needs, inclusivity, and justice. Municipalities are advised to approach the smart city concept as flexible and context-dependent, allowing strategies and policies to evolve with changing conditions.

The findings also stress the role of collaboration. While collaborative platforms can support knowledge sharing and strategic alignment, they are not a silver lining nor one-size-fits-all solution. Their contribution is contingent on context, and other institutional mechanisms may be equally or even more effective. This calls for careful management of expectations and context-sensitive design when investing in such platforms.

Moreover, this thesis emphasises the need to embed justice in governance processes from the outset. This includes ensuring transparency, citizen participation, and equitable access to resources, while addressing power imbalances that risk privileging dominant actors. Finally, by introducing the concept of dynamic capabilities into the smart city governance debate, the thesis points to the need for collaborating partners to develop adaptive organisational capacities that enable them to sense opportunities, reconfigure resources, and innovate continuously in response to fast-changing environments.

Additionally, returning once more to the core principles outlined in Section 5.2 of this thesis, the proposed governance principles are intentionally formulated at a level of abstraction that allows them to be adapted by municipalities with varying levels of resources and institutional capacity. For instance, for cities with limited financial or administrative resources, the *sociotechnical* principle does not require large-scale technological investments, but rather encourages adopting ‘low-tech’ solutions and aligning existing technologies with clearly defined social priorities. Similarly, the inclusive principle could be operationalised through targeted stakeholder engagement, transparent decision-making procedures, or the use of existing participatory fora, for instance, rather than resource-intensive digital platforms. Likewise, the temporal principle supports municipalities with constrained capacities by emphasising learning, flexibility, and gradual (institutional) adjustment over time, allowing governance arrangements to evolve organically. Taken together, these principles offer a pragmatic framework that can guide municipalities in designing and implementing context-specific smart city governance approaches, while still promoting adaptability, inclusion, and long-term orientation.

Lastly, the author of this thesis would like to point out that some of the insights generated in this thesis are already being applied in practical settings, most notably within and through the United Nations Human Settlement Programme's People-Centred Smart Cities Initiative, where the author was member of a team producing two policy reports: *Global Review of Smart City Governance Practices* (Beckers et al., 2022) and *Managing smart city governance – A playbook for local and regional governments* (Beckers et al., 2023). Additionally, the practical perspective was further strengthened by the publication of the *Smart City Code: Governance Handbook for Digital Transformation Managers in the Public Sector* (Mora et al., 2025).

6.3. Limitations and Future Research

Despite its rigour, several limitations inherent to this thesis, which open up avenues for future research, need to be acknowledged. First, the empirical analyses are tied to specific contexts, such as survey data from municipalities and manufacturing firms, which may not capture the full diversity of governance practices across regions, policy domains, and smart city actors. As a result, the generalisability of findings may be limited, particularly in settings characterised by resource constrains where governance arrangements may take forms different to those investigated in this thesis.

Second, some of the studies rely on self-reported data, which can introduce perception bias and limit the ability to capture actual behavioural or institutional change. Although steps were taken to mitigate these risks, future research could aim to uncover causal mechanisms in greater depth.

Third, while this thesis explores the role of collaborative platforms and dynamic capabilities, it does not exhaust the range of institutional and organisational arrangements that may shape smart city governance. Informal coalitions, mission-oriented governance, or alternative intermediary models may prove equally relevant but remain underexplored. Comparative research across different governance models could provide valuable insights into their relative effectiveness. To address this limitation, the author of this thesis was, at the time of writing, involved in the ongoing development of a research article that investigates governance arrangements and configurations of municipalities worldwide. Using a cluster analysis DBSCAN (density-based spatial clustering of applications with noise), the article identifies governance clusters, thereby examining approaches to governing smart cities and their institutional and organisational arrangements that extend beyond those investigated within this thesis.

Fourth, while this thesis identifies patterns and associations across different dimensions of smart city governance, it does not fully unpack the mechanisms through which these outcomes arise. A deeper understanding of how particular governance arrangements produce certain effects would require more granular exploration of organisational practices, institutional dynamics, and actor interactions. Future research could therefore benefit from qualitative or mixed-methods approaches, including in-depth case studies, to trace these mechanisms in practice. For this reason, at the time of writing, the author of this thesis was leading a research article that focusses on an in-depth case study, uncovering *how* an urban innovation intermediary implements critical innovation and intermediation functions, using the theoretical concept of tactics of implementation (see Nutt, 1986) as a theoretical lens. This article thereby directly follows up on, and complements **Article III** featured in this thesis. Additionally, the author of this thesis was part of a team of authors examining barriers to just approaches to

governing smart cities by means of a systematic literature review. In doing so, the article complements **Article I** of this thesis by identifying reasons that cause injustices in smart cities. While not featured in this thesis, the article in question was published at the beginning of 2026 (Haque et al., 2026).

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Abstract

From Challenge to Opportunity: Governance as Both Obstacle and Solution to Inclusive Smart Cities

This thesis investigates the governance of smart cities, positioning governance as a central analytical lens and both a challenge and opportunity. While technological innovation has dominated the smart city discourse, this thesis argues that governance, understood as the way decisions are made, responsibilities distributed, and collaborations organised, ultimately determines whether smart city initiatives achieve inclusive, effective, and sustainable outcomes. Through four interrelated research articles, the thesis explores how governance arrangements are conceptualised, practiced, and experienced, offering theoretical, empirical, and practical insights into how smart city governance can better address societal needs.

The thesis pursues four overarching objectives. **Objective A** seeks to understand the governance challenges constraining smart city development. Findings from a systematic literature review (Article I) and a conceptual analysis (Article II) reveal persistent conceptual ambiguity, fragmented coordination, inadequate monitoring systems, and challenges related to intermediation and multi-level governance. These gaps weaken strategic coherence and risk deepening injustices within cities. The review identifies patterns of exclusion, particularly for low-income groups, women, the elderly, and people with disabilities, whose needs are often marginalised in both decision-making and design processes. Justice therefore emerges as a central dimension for effective approaches to governing smart cities.

Objective B explores how different governance approaches can address complexity, foster collaboration, and respond to fast-changing environments. Using global survey data from municipal governments (Article III), the thesis evaluates municipally led collaborative platforms as mechanisms for coordinating multi-actor projects. Results show that such platforms enhance knowledge sharing and strategic alignment but have less consistent effects on innovation culture, competence development, and coordination across departments or governance levels. In some cases, municipalities without platforms achieve comparable or stronger results, showing the contextual nature of governance arrangements. Complementing these insights, Article IV examines survey data from Chinese manufacturing firms and shows that dynamic capabilities, understood as organisational capacities to sense, seize, and reconfigure resources, mediate the relationship between digitalisation and innovation. This finding highlights that adaptive capabilities, not only technology adoption, are crucial for translating digitalisation into innovation outcomes.

Objective C advances the theoretical foundations of smart city governance through a cross-disciplinary approach that integrates concepts from innovation management and collaborative governance theory. From innovation management, the thesis introduces sensemaking, open strategy, and technology roadmapping as tools for addressing conceptual and strategic challenges. It also applies innovation intermediation and boundary management to enhance understanding of coordination and scaling across governance levels. From collaborative governance theory, it adopts perspectives on inclusivity, joint accountability, and power relations to explain why governance structures sometimes reinforce inequalities. Together, these approaches contribute to a

more comprehensive and adaptive framework for studying governance in digital urban contexts.

Objective D synthesises the empirical and theoretical findings into three guiding principles for smart city governance: sociotechnical, inclusive, and temporal. The sociotechnical principle emphasises the co-evolution of technologies, institutions, and social needs, moving beyond technology-centred definitions. The inclusive principle calls for addressing power imbalances, ensuring participation, and embedding justice and transparency into governance design. The temporal principle highlights adaptability and reflexivity, recognising that smart city governance must evolve continuously in response to changing technological, institutional, and societal conditions.

The thesis contributes to theory by linking smart city governance to innovation management and collaborative governance, broadening the conceptual lens from technology-driven efficiency to socially responsive, adaptive, and equitable governance systems. Practically, it provides policymakers and city leaders with evidence-based insights for designing more inclusive, transparent, and context-sensitive governance frameworks. By combining theoretical reflection and empirical analysis, the thesis demonstrates that effective smart city governance depends not only on technological capability but also on the capacity to collaborate, adapt, and govern for justice in an increasingly digital urban future.

Lühikokkuvõte

Väljakutsest võimaluseni: valitsemine kui takistus ja lahendus kaasavatele tarkadele linnadele

Käesolev doktoritöö uurib nutikate linnade valitsemist, käsitledes kui keskset analüütilist läätse, ja kui nii väljakutset kui ka võimalust. Kui senises arutelus on nutika linna kujundamisel domineerinud tehnoloogilised uuendused, siis see töö väidab, et tegelikult määrab just valitsemine – see, kuidas otsuseid tehakse, vastutust jaotatakse ja koostööd korraldatakse – selle, kas nutika linna algatused saavutavad kaasavad, tõhusad ja kestlikud tulemused. Nelja omavahel seotud teadusartikli põhjal uurib väitekiri, kuidas valitsemise korraldused on mõtestatud, praktikas rakendatud ja kogetud, pakkudes nii teoreetilisi, empiirilisi kui ka praktilisi teadmisi, kuidas nutika linna valitsemist saab paremini suunata ühiskondlike vajaduste rahuldamiseks.

Tööl on neli peamist eesmärki. **Eesmärk A** on mõista valitsemise väljakutseid, mis takistavad nutikate linnade arengut. Süsteemne kirjanduse ülevaade (Artikkel I) ja kontseptuaalne analüüs (Artikkel II) toovad esile püsiva kontseptuaalse ebaselguse, killustunud koordineerimise, ebapiisavad seiresüsteemid ning väljakutsed vahenduse ja mitmetasandilise valitsemisega. Need puudujäägid nõrgestavad strateegilist sidusust ja süvendavad ebaõiglust linnades. Ülevaade näitab, et eriti naised, eakad, madala sissetulekuga rühmad ja puudega inimesed on sageli otsustusprotsessidest välja jäetud ning nende vajadusi ei arvestata. Õiglus tõuseb esile nutikate linnade juhtimise tõhusate lähenemisviiside keskse mõõtmena.

Eesmärk B uurib, kuidas erinevad valitsemisviisid aitavad toime tulla keerukuse, koostöö ja kiiresti muutuvate keskkondadega. Ülemaailmsete linnavalitsuste küsitlusandmete põhjal (Artikkel III) analüüsitakse omavalitsuste juhitud koostööplatvorme kui mehhanisme, mis toetavad mitme osapoole koostööd. Tulemused näitavad, et sellised platvormid soodustavad teadmiste jagamist ja strateegilist ühtlustamist, kuid nende mõju innovatsioonikultuurile, kompetentside arendamisele ja valitsemistasandite vahelisele koordineerimisele on ebaühtlane. Mõnel juhul saavutavad platvormideta omavalitsused sarnaseid või isegi paremaid tulemusi, mis rõhutab valitsemise kontekstitundlikkust. Täiendavalt uurib Artikkel IV Hiina tootmisettevõtete uuringuandmeid ja näitab, et dünaamilised võimekused, mida mõistetakse kui organisatsioonilist võimekust ressursse tajuda, haarata ja ümber kujundada, vahendavad digitaliseerimise ja innovatsiooni vahelist suhet. Uurimise tulemus rõhutab, et digitaliseerimise innovatsiooni tulemusteks muutmisel on ülioluline mitte ainult tehnoloogia omaksvõtmine, vaid ka kohanemisvõime.

Eesmärk C edendab nutika linna juhtimise teoreetilisi aluseid interdistsiplinaarse lähenemisviisi kaudu, mis ühendab innovatsioonijuhtimise ja koostööl põhineva juhtimise teooria kontseptsioone. Lisaks rakendatakse innovatsioonivahendamise ja piirihalduse põhimõtteid, et paremini mõista koordineerimist ja skaleerimist erinevate valitsemistasandite vahel. Koostöövalitsemise teooria pakub seevastu raamistiku kaasamise, vastutuse ja võimusuhte tasakaalu analüüsimiseks, selgitades, miks valitsemisstruktuurid võivad mõnikord tugevdada ebavõrdsust. Üheskoos loovad need lähenemised terviklikuma ja kohanemisvõimelisema raamistiku nutika linna valitsemise uurimiseks.

Eesmärk D sünteesib empiirilised ja teoreetilised tulemused nutika linna juhtimise kolmeks juhtpõhimõtteks: sotsio-tehniliseks, kaasavaks ja ajaliseks. Sotsio-tehniline

põhimõte rõhutab tehnoloogiate, institutsioonide ja sotsiaalsete vajaduste koosarengut, liikudes kaugemale tehnoloogiakesksetest definitsioonidest. Kaasav põhimõte kutsub üles vähendama võimuerinevusi, tagama osalust ning integreerima õiglust ja läbipaistvust valitsemisse. Ajaline põhimõte rõhutab kohanemisvõimet ja paindlikkust, tunnistades, et nutika linna valitsemine peab pidevalt arenema vastavalt muutuvatele tehnoloogilistele, institutsionaalsetele ja ühiskondlikele tingimustele.

Töö panustab teooriasse, ühendades nutika linna valitsemise innovatsioonijuhtimise ja koostöövalitsemisega ning laiendades arusaama tehnoloogiliselt juhitud tõhususest sotsiaalselt tundlikuks, kohanemisvõimeliseks ja õiglaselt toimivaks valitsemissüsteemiks. Praktiliselt pakub see poliitikakujundajatele ja linnajuhtidele tõenduspõhiseid teadmisi, kuidas kujundada kaasavamaid, läbipaistvamaid ja kontekstitundlikumaid valitsemisraamistikke. Teoreetilise refleksiooni ja empiirilise analüüsi kombineerimise abil näitab töö, et tõhus nutika linna valitsemine sõltub mitte ainult tehnoloogilisest suutlikkusest, vaid ka võimest teha koostööd, kohaneda ja valitseda õiglaselt üha digitaalsemas linnakeskkonnas.

Appendix

Publication I
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A systematic review of research on just, equitable, responsible, and inclusive smart cities

Md. Nazmul Haque [a,b,1], Dominik Beckers [c,d], Emilio Costales [e,f], Samar Aad [g], Ayyoob Sharifi [h,i,2,*], Luca Mora [c,j]

[a] Urban Environmental Science Lab (URBES), Graduate School of Humanities and Social Sciences, Hiroshima University, Japan
[b] Department of Urban and Regional Planning, Khulna University of Engineering & Technology, Khulna, Bangladesh
[c] Academy of Architecture and Urban Studies, Tallinn University of Technology, Tallinn, Estonia
[d] FinEst Centre for Smart Cities, Tallinn University of Technology, Estonia
[e] Executive Business Centre, University of Greenwich, United Kingdom
[f] Unity Lab, University of Edinburgh-Napier, United Kingdom
[g] AKSOB, Management Department, Lebanese American University, Lebanon
[h] The IDEC Institute & Network for Education and Research on Peace and Sustainability (NERPS), Hiroshima University, Higashi-Hiroshima, Japan
[i] School of Architecture, Design and Planning, The University of Queensland, Brisbane, 4067, Australia
[j] The Business School, Edinburgh Napier University, Edinburgh, Scotland, United Kingdom

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ABSTRACT

Digital technologies and infrastructure are essential to the development of smart cities. Yet, vulnerable populations often lack equitable access to such resources. In this context, integrating justice into smart city development serves as a crucial foundation for developing just and equitable cities. To explore this issue, we examined 3067 articles and synthesized findings from 67 studies on justice in smart cities. Using deductive content analysis, we categorize justice issues into two distinct groups: types and dimensions. Among the various types of justice, infrastructural justice emerges as the most frequently discussed, appearing in 23 studies and highlighting significant disparities in access to basic urban infrastructure for marginalized communities. In terms of justice dimensions, procedural justice is the most prominent. Discussed in 27 studies, it emphasizes the importance of inclusive decision-making and the challenges posed by limited public awareness and tokenistic participation. The findings reveal that marginalized communities, particularly low-income groups, women, and individuals with disabilities, bear the brunt of exclusion, inequity, and marginalization in smart city developments. These communities are particularly vulnerable to gentrification, displacement, and reduced economic opportunities, further deepening existing inequalities. By positioning justice as a central element in smart city development, this study calls for a fundamental shift in the mindset of practitioners, advocating for policies and governance approaches that promote a just, equitable, responsible, and inclusive smart city ecosystem.

1. Introduction

Worldwide, cities have deployed technologies and digital solutions to improve the quality and efficiency of their infrastructure and services (Beckers et al., 2022, 2023). These solutions include sensor-based data collection for informed decision-making (Mao et al., 2020). They also involve new technologies and service provision models that reshape interactions between city service providers and users (Micozzi & Yigitcanlar, 2022; Sharifi et al., 2025). Additionally, collaborative efforts between public and private actors (Thabit & Mora, 2023) align with the concept of 'governance-beyond-the-state' (Swyngedouw, 2005, p. 1991) and illustrate how digital innovation is transforming urban

* Corresponding author. Network for Education and Research on Peace and Sustainability (NERPS), 1-5-1 Kagamiyama, Higashi- Hiroshima City, Hiroshima, 739-8529, Japan.
E-mail addresses: d220635@hiroshima-u.ac.jp, nhaque13@urp.kuet.ac.bd (Md.N. Haque), dominik.beckers@taltech.ee (D. Beckers), E.Costales@greenwich.ac.uk (E. Costales), samar.makhoul@lau.edu.lb (S. Aad), sharifi@hiroshima-u.ac.jp, sharifigeomatic@gmail.com (A. Sharifi), luca.mora@taltech.ee (L. Mora).
[1] https://orcid.org/0000-0003-3988-5654
[2] https://orcid.org/0000-0002-8983-8613

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management. This new "digital era government" (Dunleavy et al., 2006, p. 467) has pushed local governments to integrate data-driven decision-making as a core function of governance, rather than just a tool for supporting specific industries and their digital innovations (Tonnarelli & Mora, 2025). Understanding digital transformation requires exploring how new digitally-enabled institutional arrangements emerge, spread and ultimately gain acceptance and legitimacy within institutional contexts (Hinings et al., 2018). While conceptual definitions are still subject to clarification, a smart city is generally understood as an urban innovation framework that leverages digital technologies, skilled human resources, and effective governance structures to improve the socio-economic and environmental conditions of urban residents (Meijer & Bolívar, 2015). By integrating information and communication technologies (ICT) across various sectors, smart cities aim to reshape urban models by enhancing the efficiency and quality of municipal systems through digital solutions (Bjørner, 2021). This technological integration has positioned ICT as a central force in urban transformation, reinforcing the long-standing view that smart city development is primarily driven by technology (Gil-Garcia et al., 2015). In their analysis of smart city development paths, Mora and Deakin (2019) highlight that much of the literature follows a techno-centric interpretation, arguing that "ICT and market perspectives represent the primary driving forces shaping smart cities, which are the result of a massive input of technological solutions in the built environment" (p. 111). However, while these digital innovations play a crucial role in advancing urban infrastructure, their dominance has often come at the cost of social and democratic values, raising concerns about the broader implications of smart city projects (Alizadeh & Sharifi, 2023a).

In response to this often-witnessed techno-centricity, Mora and Deakin (2019) also reveal a growing, albeit comparatively limited, body of literature that opposes this view and instead advocates for a perspective that envisions smart cities as complex socio-technical systems where technological advancements align with human, social, cultural, economic, and environmental considerations. This holistic interpretation of smart cities has gained increasing recognition in academic discourse and practical implementations (see Lykouras & Mora, 2025). For instance, Alizadeh and Sharifi (2023b) show that in scholarly debates, the "social dimension of smart cities" (p. 2) is primarily explored through the lenses of justice, e-democracy, cultural resilience, participatory governance, citizen-centricity, and social sustainability. Costales (2022) approaches the smart city concept from a social innovation perspective, contending that social innovation is central to the concept as it offers a pathway to address unmet needs overlooked by the market or the state, foster new institutional relationships, and empower individuals to reshape existing structures. In addition, Kim et al. (2021) assert that "smart cities are the spatial outcome of technological and social innovations and in turn, they are platforms to facilitate innovations" (p. 25) for the benefit of their citizens, therefore, empowering marginalized and underrepresented segments of the population. This aligns with the principle of justice, which is central to the development of smart cities. In this context, justice embodies a concerted effort to build strong, accountable institutions, address inequalities, and ensure access to essential amenities regardless of socioeconomic status, race, ethnicity, gender, or ability (Haque & Sharifi, 2024a, 2024b). A just approach to smart city development aims to ensure fair access to digital infrastructure, affordable services, and innovative tools while fostering resilient systems that adapt sustainably to environmental, economic, and social challenges (Kolotouchkina et al., 2024; Rosol & Blue, 2022; Sharifi, Amirzadeh, & Khavarian-Garmsir, 2025).

Yet, most research and practical implementations of smart city development remain predominantly focused on economic and environmental dimensions, often through a techno-centric lens, while frequently neglecting justice dimensions (Chen et al., 2022). Moreover, the literature on smart cities lacks comprehensive syntheses, often addressing justice-related topics in isolation rather than through an integrated approach. For instance, Breuer et al. (2019) engage in a discussion on the 'right to the smart city,' building on Lefebvre's (1967) argument for the 'right to the city.' However, their discussion remains confined to a conceptual level and lacks guidance for incorporating justice dimensions. Similarly, Marimuthu et al. (2022) reviewed the literature on technology adoption frameworks to build "an adoption conceptual framework that integrates community value thought in the context of participatory smart city applications" (p. 1). Shamsuddin and Srinivasan (2021) also examined scholarly works and revealed that only a few have utilized ICT data to investigate housing challenges faced by economically vulnerable, historically marginalized communities. Additionally, Chen (2022) offers a perspective suggesting that urban happiness, linked to welfare, health, and quality of life, serves as the gateway to transforming smart cities into sustainable living spaces. Lastly, Turoń and Tóth (2023) highlight how innovation in shared mobility is perceived in scientific literature.

Overall, despite growing concerns about the marginalization of specific citizen groups in smart city strategies (Kolotouchkina, Ripoll González, & Belabas, 2024; Sharifi, Allam, Bibri, & Khavarian-Garmsir, 2024), existing research remains fragmented. It lacks a systematic exploration and a conceptual framework to guide governance structures that ensure justice and its key subdimensions - equity, responsibility, and inclusivity. This gap hinders the development of comprehensive governance frameworks that support and inform inclusive action in smart city development. While governance is widely acknowledged as central to smart city development (Sharifi, 2019), if not approached through a justice-oriented lens, it can ultimately hinder the realization of truly inclusive and equitable urban futures (Alizadeh & Sharifi, 2023b).

To address these shortcomings, this systematic literature review thoroughly examines the research landscape on justice in smart cities. By highlighting justice considerations and disparities in smart city initiatives, we aim to offer critical insights that can shape future research, governance approaches and policy, ultimately fostering more equitable and inclusive urban solutions. As part of this effort, we explicitly examine which stakeholders are affected by justice-related issues in smart cities and how they are impacted. This focus helps illuminate how governance structures can be designed or reformed to support justice more effectively. Specifically, with this review article, we seek to answer the following questions.

- What is the current status of research on smart cities in relation to justice?
- Who are the stakeholders impacted by justice-related issues in smart cities, and how are they affected?

We aspire to advance both theoretical and practical discussions on the role of justice in smart city development. Theoretically, we aim to contribute to advancing contemporary debates beyond the prevailing techno-centric narratives by integrating a justice-oriented perspective into smart city governance that accounts for the socio-technical complexities of urban digital transformation. Practically, we seek to offer actionable insights that help policymakers and practitioners to embed justice as a fundamental principle in smart city development, thereby ensuring more equitable, inclusive, and context-sensitive urban futures.

2. Theoretical background

Addressing justice in smart city development can yield several benefits. For instance, Chen et al. (2022) suggest that prioritizing residents' knowledge and skills over technology cultivates inclusion and respects their rights to belong and participate. Such projects can also empower citizens to engage in political discussions about urban development, promoting a more informed and cohesive society. Similarly, Alizadeh and Sharifi (2022, 2023a) propose that a just approach to smart cities can reduce vulnerabilities and expedite recovery in exposed communities while fostering cultural resilience and promoting fair

opportunities. This, in turn, supports equitable access to smart tools and facilities. Furthermore, it is proposed that smart cities can harness the power of participatory governance to develop solutions that nurture a democratic and inclusive environment, thereby promoting social resilience and building social capital (Suleimany et al., 2022; Thabit et al., 2024).

To explore this promise and assess justice in smart city research, we establish a conceptual framework that distinguishes between various notions of justice. Justice is central to ensuring that smart city initiatives do not exacerbate existing inequalities but instead promote inclusivity, fairness, and ethical governance. However, the interchangeable use of justice-related terms often leads to conceptual ambiguity in research and policy discussions. A structured taxonomy promises to provide the much-needed clarity and systematic analysis to address this challenge. This review adopts the taxonomy proposed by Haque and Sharifi (2024a), which distinguishes between 'justice types' and 'justice dimensions' to offer a more precise understanding of justice in smart cities. Justice types – such as social, environmental, mobility, ecological, and infrastructural justice – categorize the domains where justice concerns arise, ensuring that smart cities align with people's needs and demands. In contrast, justice dimensions – distributional, procedural, recognitional, and restorative – serve as analytical tools for assessing how justice is incorporated into smart city policies and practices (Table 1). By integrating this taxonomy, the review facilitates a more structured and case-specific analysis, ensuring that ethical considerations are embedded within smart city development. Thereby, this approach bridges theoretical justice discussions with practical policy applications, thereby strengthening the foundation for a more just and responsible smart city paradigm.

While the taxonomy of justice types and dimensions provides a conceptual foundation for assessing fairness in smart cities, ethical concerns highlight the practical challenges of implementing justice in a rapidly digitizing urban landscape (Alizadeh & Sharifi, 2023a). Therefore, this review also considers various ethical concerns related to smart cities (see Table A2 for details). According to extant discussions in contemporary literature, key ethical concerns are privacy, surveillance, and the digital divide that could disproportionately impact societal groups, making it essential to ensure that smart city initiatives align with principles of transparency, accountability, and inclusive governance. Furthermore, biased algorithms and misinformation can skew decision-making processes, undermining procedural and recognitional justice, while security, data sovereignty, and environmental ethics safeguard individual rights and promote sustainable urban development. By keeping justice frameworks as the central theme and linking them with ethical considerations, this review underscores the need for a holistic approach to smart city research (Alizadeh & Sharifi, 2023b).

In addition to exploring various justice types, dimensions, and ethical considerations, this review also differentiates between marginalized groups (Table 2) that may be affected by injustices in smart cities. This distinction is important as the use of technology in urban spaces can cause "socio-economic disparities to continue to worsen" (Voorwinden & Ranchordas, 2021, p. 8) and disproportionately impact marginalized groups (Kitchin et al., 2018). Extant literature suggests that ignoring the unique needs, skills, resources, and abilities of marginalized and vulnerable groups can ultimately result in their systematic exclusion or marginalization from urban policies and discussions (Kolotouchkina et al., 2023, 2024; Rosales & Fernández-Ardèvol, 2020). The soceital groups considered in this study are listed in Table 2.

While justice frameworks and ethical considerations provide a foundation for understanding fairness and inclusivity, addressing sector-specific challenges is essential to translating these principles into practical solutions. Different sectors – such as energy, water, waste, transportation, and governance – shape urban experiences in distinct ways, often reinforcing or mitigating existing inequalities. A sectoral focus allows for a more nuanced analysis of how smart city technologies impact societal groups, identifying both opportunities for empowerment and risks of exclusion. By exploring key areas like health, education, and infrastructure, this review assesses how digital solutions can bridge gaps in access to essential services while ensuring that technological advancements promote social justice. Additionally, considering the interconnections between sectors – such as the water-energy-food nexus – enables a more integrated and inclusive approach to smart city development (Kitchin et al., 2018). For this review, we relied on sectoral categories identified by Kitchin et al. (2018). The details can be found in Table A2.

Another important element of a smart city is its dimensions, which represent broader, more integrated aspects of urban life that span across multiple sectors and emphasize the overall well-being of citizens. These dimensions – Living, Mobility, Data, Economy, Environment, People, and Governance – explore how technological advancements in various sectors interact to influence social equity, inclusivity, and justice within a city (Giffinger et al., 2007; Sharifi, 2019; Ulya et al., 2024).

The above-mentioned categories and classifications have guided the development of the protocol that was used for data extraction and content analysis. More details are provided in the next section.

Table 1
Justice types and justice dimensions.

Justice types, derived from (Calderón-Argelich et al., 2021; Haque & Sharifi, 2024a; Pineda-Pinto et al., 2022; Schlosberg, 2013; Zuniga-Teran et al., 2021).	
Environmental Justice	Ensures fair distribution of environmental benefits and burdens, protecting vulnerable communities from disproportionate negative impacts.
Social Justice	Promotes equitable access to resources and opportunities in smart cities.
Mobility Justice	Ensures promoting societal value and leading a better life by participating in smart city initiatives.
Ecological Justice	Advocates for protecting non-living entities and ecosystems in smart cities as well.
Infrastructural Justice	Focuses on rectifying historical inequalities caused by outdated urban infrastructure.
Justice dimensions, derived from (Anguelovski et al., 2020; Calderón-Argelich et al., 2021; Haque & Sharifi, 2024a; Langemeyer & Connolly, 2020; Schlosberg, 2013; Zuniga-Teran et al., 2021)	
Distributional Justice	Ensures fair allocation of urban benefits and services for all citizens.
Procedural Justice	Promotes fair, inclusive decision-making in smart city governance.
Recognitional Justice	Acknowledges and integrates diverse social group needs in urban planning.
Restorative Justice	Addresses and corrects past social inequalities in urban planning.

Table 2
Societal groups potentially impacted by injustices in smart cities.

Vulnerable societal groups, derived from Haque and Sharifi (2024b); NBAC (2001)	
Low-income	Face financial barriers to accessing urban services in smart cities.
Ethnic Minorities	Encounter discrimination or language barriers in accessing urban amenities.
Older People	Struggle with limited access to age-appropriate infrastructure and services.
Physically challenged people	They face difficulties accessing inclusive urban infrastructure and may require wheelchair-friendly spaces and so on.
Children	Experience barriers to safe, inclusive facilities crucial for their development.
Women	Face gender-based barriers to resources, services, and safety in urban spaces.
Specific Occupational Group	Certain vulnerable occupational groups face challenges in supporting their livelihoods.

3. Materials and methods

3.1. Procedure for identifying relevant studies

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Fig. 1) for literature search and selection. To identify relevant studies, we developed a comprehensive search string incorporating keywords related to smart cities and justice-related themes. The initial search string was formulated based on previous review studies in this field and further refined by reviewing preliminary search results and incorporating additional relevant terms where necessary. The final search string included: ((“smart cit*”) AND (“Inclusiv*” OR “Fair” OR “Fairness” OR “Transparen*” OR “Equit*” OR “Equal*” OR “Accessib*” OR “Responsib*” OR “Just*” OR “Impartial*” OR “Ethic*”)). The complete search string is provided in the Appendix (e-component). The search was conducted in Web of Science (WoS) and Scopus. The search query targeted the Title, Abstract, and Keywords fields to gather a focused and relevant dataset. In early 2024, the search retrieved 1361 articles from WoS and 1706 from Scopus, resulting in 3067 records.

To ensure the dataset’s quality and relevance, we included only peer-reviewed journal articles written in English that focus on empirical studies. We did not impose any restrictions on the year of publication to maintain an inclusive dataset. After removing duplicates and excluding non-English articles, a total of 1850 articles remained in our review database. These articles underwent a title and abstract screening by the authors, retaining only those studies that met the following inclusion criteria: (1) a clear focus on smart cities, (2) a specific emphasis on justice-related issues, and (3) relevance to urban contexts. During the initial title screening, 293 papers were identified as relevant. At this stage, papers were excluded if they did not include a case study (1522), were not original research (20), were not written in English (6), could not be retrieved (6), or had been retracted (3). In the next step, the remaining 293 articles were distributed among different co-authors for a second round of review, applying the second and third inclusion criteria. During this process, the authors discussed disagreements on article inclusion and reached a consensus, ensuring a reliable final dataset. This process resulted in a final selection of 67 papers that precisely aligned with our review questions. In this final exclusion step, we critically examined the full texts of each article and included only those that addressed justice as a central concept in smart city research, particularly in connection with themes of responsibility, equity, inclusivity, and ethical considerations. Fig. 1 provides a detailed overview of the data extraction process.

3.2. Techniques for extracting and interpreting data

To extract the required data and analyze the content of the selected papers, we developed a review protocol based on deductive content analysis. This protocol is primarily grounded in the literature we reviewed and considers the theoretical framework related to smart cities, as discussed in Section 2 (see the e-component for details). We then

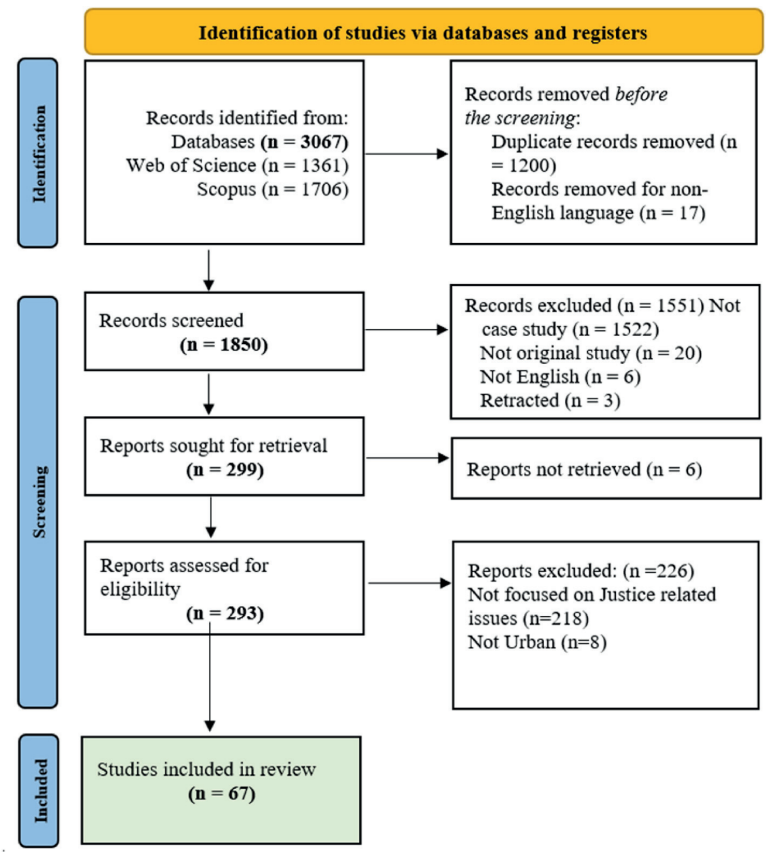

Fig. 1. PRISMA flowchart outlining the article identification process (Page et al., 2021).

carefully examined the contents of the articles based on this protocol. Initially, we adopted a trial-and-error approach to ensure accuracy and consistency in the data extraction process. Within this process, each co-author independently extracted data from two full articles, which the lead author then reviewed. The lead author compared the extracted information with his own records and provided feedback to maintain coherence across all co-authors. This iterative process refined the literature sorting procedure, making it more transparent, systematic, and accountable to meet the required academic standards. Moving forward, we first extracted a general overview of each article, including case city, country, and geographical focus (with sub-regions, where applicable) following Table 3. Next, we identified societal groups underrepresented in smart city research, following the earlier categorization by Haque and Sharifi (2024b) and NBAC (2001). This information was further enriched by analyzing ethical considerations related to smart cities.

Table 3
Structured framework to extract data.

Entries	Data required	References
Case city	Studied city name	N/A
Case country	Studied country name	N/A
Geographical identity	Asia, Africa, Europe, Americas, Oceania, generic	(United Nations Geoscheme)
Justice regarding what societal groups	Migrants, Elderly, Children, Physically challenged people, Low-income, Minorities, Women, LGBT, Sex Workers, Refugees, Homeless, Specific occupational groups (either urban farmer, foragers, etc), Mentally challenged, Generic	(Lynam & Cowley, 2007; NBAC, 2001; Pratt, 2019)
Specific aspect of ethics	Privacy, Misinformation, Biased algorithms, Digital divide, Transparency, Accountability, Public participation (inclusive governance), Security, Data sovereignty, Environmental ethics, Cultural and social impacts, Generic	(Forum, 2021; Ziosi et al., 2023)
Main Justice type	Environmental, Social, Ecological, Infrastructural, Mobility, Generic	(Calderón-Argelich et al., 2021; Haque & Sharifi, 2024a; Schlosberg, 2003)
Main Justice dimension	Distributional, Procedural, Generational, Commutative, Restorative, Recognitional, Generic	(Haque & Sharifi, 2024a; Schlosberg, 2013)
Main sectoral focus	Energy, Water, Waste, Nexus (between multiple sectors, e.g., water and energy, food and water and energy), Food, Transportation, Education, Governance and administration, Health, Telecommunication and information technology (smart city, digital infrastructure), Green/blue infrastructure, Infrastructure (other than energy, water, transport, telecommunication, and green/blue infrastructure), Tourism and recreation, Manufacturing, Construction and housing, Agriculture (farming, fishing), Mining and extraction, Forestry, Business, Financial and insurance, Real estate, Research and development, Data (e.g., data center, cloud computing), Culture and art	Kitchin et al. (2018)
Main smart city dimensions	Living, Mobility, Data Economy, Environment, People, Governance, Generic	Ulya et al. (2024)

These ethical aspects were categorized into personal and collective ethical concerns, highlighting issues such as the digital divide, data fabrication, and technological biases.

Following that, we focused on the concepts of justice in relation to social groups and smart city research. We took note of various justice types and dimensions, as outlined in Table 1. Furthermore, we extracted information on the main sectoral focus of smart city initiatives to enhance our dataset and address the review questions. We also compiled information on key smart city dimensions to assess how smart city research addresses inclusivity, responsibility, and justice among societal groups. For an overview of our data extraction strategy, please refer to Table 3.

Finally, in accordance with the review protocol detailed in Table 3, we structured our data extraction process using a Microsoft Excel spreadsheet. To analyze the collected data, we applied basic descriptive statistical methods.

4. Results

4.1. Current landscape of 'Just' smart cities research

This section provides an overview of the landscape and trends related to the reviewed literature. Regarding country-specific contributions, our database shows that the USA leads in the number of studies, followed by India, Canada, and Indonesia (Fig. 2a). This distribution reflects both the well-established research ecosystems in North America and the growing academic contributions from Asian nations, particularly India and Indonesia. While this trend signals a positive shift toward more geographically diverse perspectives, research on justice in smart cities remains predominantly concentrated in the Americas. To understand the broader distribution of research, we also examined contributions at a continental scale, analyzing case studies from Africa, the Americas, Asia, Europe, and Oceania. Within these regions, subregional categorizations further highlight the geographical breadth and depth of research, as illustrated in Fig. 2b. However, contributions from certain regions remain scarce.

While geographical coverage remains uneven, the temporal trends in publication output reveal a growing scholarly interest in justice in smart cities. An analysis of the publication timeline reveals a notable increase in scholarly attention to this field over the past decade, as shown in Fig. 2c. While 2013 and 2014 saw only isolated publications, there was a modest rise from 2017 to 2019. However, from 2020 onward, the number of studies grew steadily, with 2023 marking the most significant increase. The analysis indicates that Taylor & Francis is the dominant publisher, followed by Elsevier and SAGE Publications. Among the leading journals, Urban Planning (3 articles), International Journal of Urban Sciences (2 articles), Smart Societies (2 articles), and Sustainability (2 articles) stand out as key platforms for scholarship in this domain.

As scholarly attention to justice in smart cities has increased over time, the thematic focus of these studies has also evolved. In examining the justice themes explored in the literature, we identified two main categories: types and dimensions. This framework (see Fig. 3a) provides a lens to evaluate how justice concerns manifest in various urban contexts and highlights the interplay between thematic types and dimensions in addressing urban inequalities. Under justice types, infrastructural justice was the most frequently discussed, appearing in 23 articles. Social justice followed and was highlighted in 19 studies, with examples focusing on the role of participatory platforms in addressing inequality. Mobility justice, while less common (9 studies), underscored the inequities in urban transport systems, such as accessibility for individuals with disabilities and low-income status. Environmental and ecological justice remain notably overlooked in smart city literature: only four articles address environmental justice (e.g., urban green-space distribution) and a single one focuses on the ecological aspect. Our analysis suggests that this may stem from the predominant

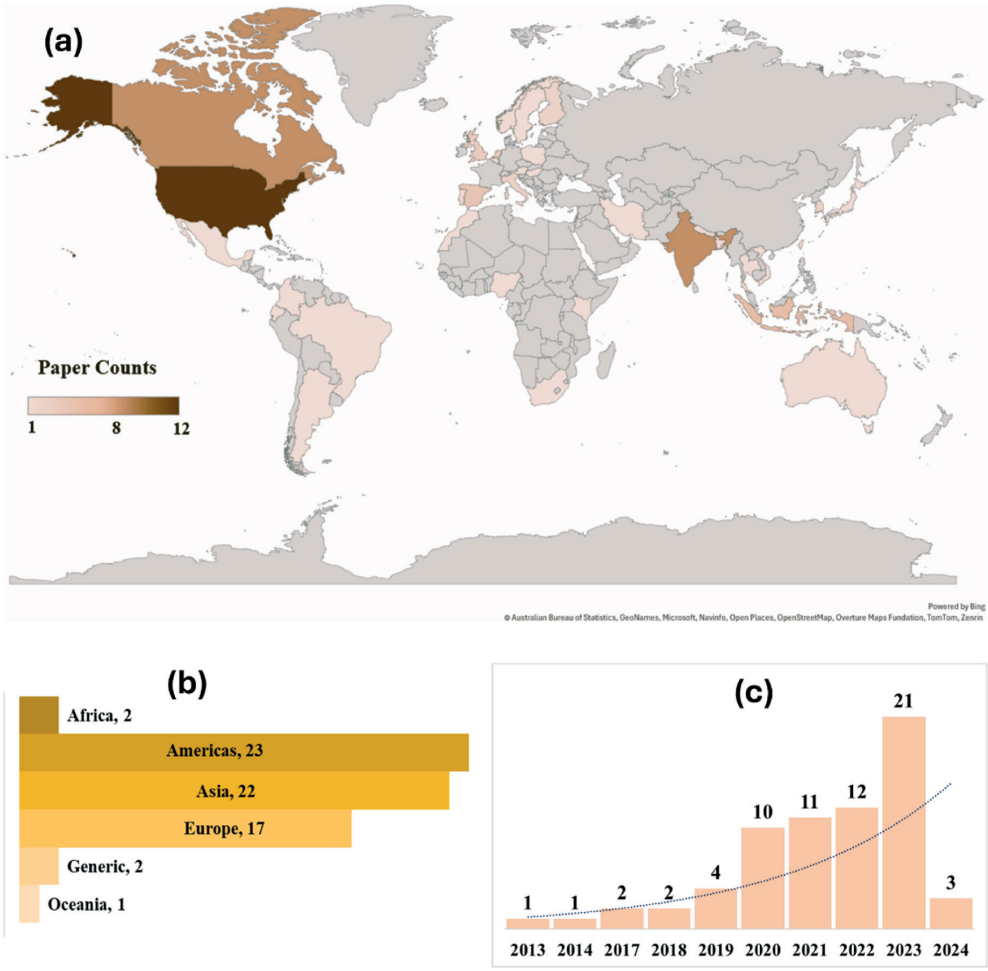

Fig. 2. Geographical distribution of published literature on smart city research (a) country-wise, (b) region-wise, and (c) publication trend. Since we explored data up to early 2024, the numbers are relatively low for 2024.

emphasis on human-centered technological advancement, which often sidelines ecological systems and non-human entities. Indeed, to date, much smart city research has failed to consider the equitable distribution of environmental burdens and benefits across all communities, including both human and non-human ones (Tomitsch et al., 2021). This is a surprising finding, given the critical importance of environmental sustainability and ecological balance in urban development (Haque & Sharifi, 2024a, 2024b).

Among the justice dimensions, procedural justice was the most frequently addressed (27 articles), with an emphasis on inclusive decision-making processes. Distributional justice also featured prominently (25 articles), focusing on the unequal allocation of resources among demographic groups. Recognitional justice appeared in 11 studies, highlighting the marginalization of underrepresented communities in smart city policies. Restorative justice was the least explored, discussed in only three articles, and centered on reconciliation mechanisms in post-conflict urban settings. Based on our review, we argue that this is likely due to smart city narratives being future-focused and innovation-driven, which often omit critical reflections on historical injustices or policy exclusions – the core components of restorative justice (Fletcher, 2020).

Regarding sectoral foci (Fig. 3b), governance and administration (21 articles) emerged as the most discussed sector, highlighting the growing emphasis on inclusive and equitable decision-making in smart city initiatives. Telecommunications (10 articles) underscores the role of digital connectivity in ensuring accessibility and efficiency. Infrastructure (8 articles) remains a critical component, addressing urban planning and service delivery gaps that directly impact social equity. In addition, the temporal trend (Fig. A1a, e-component) indicates that the rising focus on governance and administration in 2023–2024 signals a broader shift from traditional infrastructure-based approaches to more data-driven and participatory governance models. This transition is particularly evident in regions with strong digital infrastructures and institutional capacity, which are driving the shift toward more inclusive and justice-oriented frameworks in smart city research.

In terms of smart city dimensions, the analysis revealed varying levels of attention, with governance emerging as the most prominent, discussed in 27 articles (Fig. 3c). According to the reviewed literature, governance is crucial, as equitable decision-making and participatory frameworks are key to addressing systemic inequities and ensuring

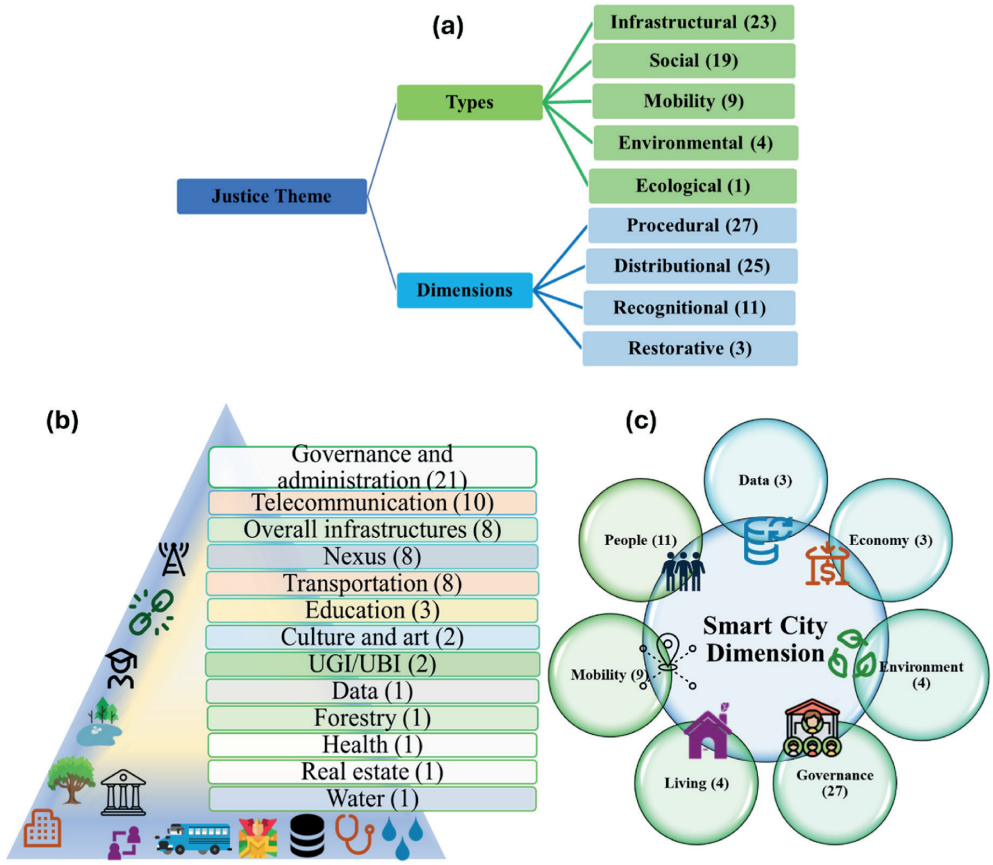

Fig. 3. (a) Justice theme, (b) Sectoral focus areas, and (c) Key smart city dimensions derived from the reviewed literature on smart cities. ((The icons are freely available at https://www.flaticon.com/).

inclusivity in smart city development. Other dimensions include People (11 articles), Mobility (9 articles), and Environment (4 articles), highlighting the growing focus on social inclusion, transportation, and sustainability. The Living dimension was discussed in 4 articles, focusing on the quality of housing and basic amenities. Finally, Data, Economy, and Generic dimensions were each represented in 3 articles, indicating a relatively lower focus on the ethical use of data and broader conceptual frameworks in smart city discourse. A temporal observation reveals that since 2023, the inclusion of multidimensional dimensions has gained prominence, further underscoring the need to address justice alongside existing technocentric improvements (Fig. A1b, e-component). For detailed information regarding the database we analyzed, please see Table A2 in the e-component.

4.2. How justice connects with smart city features and sectors

This section examines the intersection of various justice themes with smart city dimensions, highlighting governance structures, sectoral biases, and the risks associated with limited interventions in different regions (refer to Table A1, e-component, for the cross-sectional information on these issues). By emphasizing justice-centered frameworks, we recognize both the beneficiaries and those who are marginalized in smart cities.

In the Americas, concerns about justice within smart city initiatives are particularly noticeable in the governance and urban mobility dimensions (Fig. 4). The majority of research highlights the infrastructural justice deficits that arise from public-private partnerships and decision-making processes, which often prioritize efficiency and innovation over inclusion. For instance, Baibarac-Duignan and de Lange (2021) illustrate how urban development projects often benefit private interests at the expense of marginalized communities that lack the institutional leverage to influence city planning. These concerns often revolve around procedural and distributional justice dimensions, highlighting the tension between delivering public services equitably and adhering to market-driven governance models. Urban mobility further exemplifies these justice-related challenges. Gentrification and escalating transportation costs often contribute to exclusionary patterns that disproportionately affect low socioeconomic status (SES) groups. These dynamics highlight critical issues in relation to procedural justice, as marginalized populations are frequently excluded from meaningful participation in transportation planning, for instance. Therefore, the findings underscore the urgency of addressing these inequities by calling for mobility solutions that are both affordable and inclusive (Jeghers et al., 2024). Moreover, social justice emerges as a critical theme in discussions about smart city development, particularly concerning governance structures and administrative priorities in the Americas. Here, governance plays a pivotal role in shaping how urban resources and services are allocated, determining whether development outcomes are inclusive or exacerbate existing inequalities. For instance, the lack of institutionalized citizen engagement often reinforces power

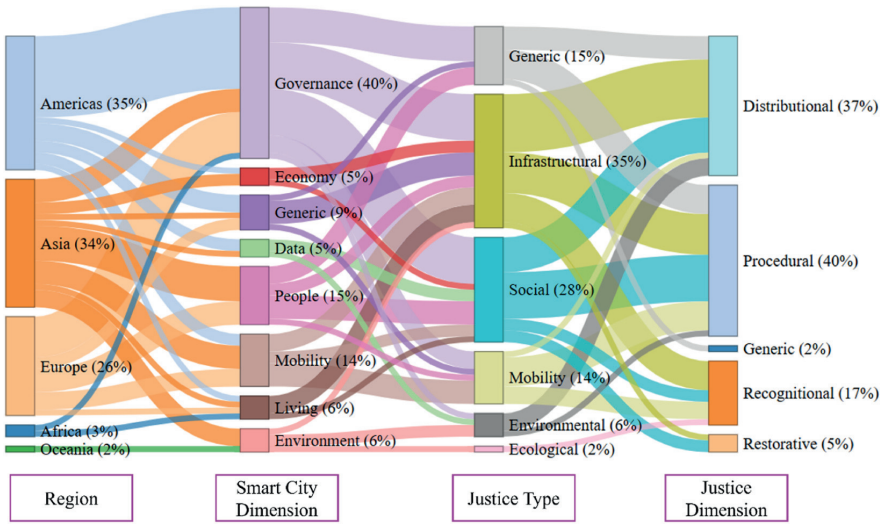

Fig. 4. Multidimensional patterns derived from the database, highlighting how different regions engage with smart city dimensions in relation to core justice themes.

asymmetries, privileging private actors and limiting the influence of underrepresented communities (see van Gils & Bailey, 2023).

In addition to governance and mobility, information and communication technologies (ICTs) are increasingly shaping the outlines of justice in smart cities in the Americas. Historical case studies, such as those from Montgomery and Chattanooga in the U.S., illustrate both the promise and the peril of data-driven urban development (Fletcher, 2020). While technological solutions have the potential to empower historically neglected communities and support socioeconomic uplift, they can also entrench existing disparities if implemented without a justice-oriented framework. Digital infrastructure gaps further exacerbate these risks, as unequal access to technology can limit the participation of marginalized groups in civic, social, and economic life (Lung-Amam et al., 2021). These issues connect closely to recognitional justice, which emphasizes the importance of acknowledging and addressing the diverse needs and identities present within urban populations.

In Europe, the discourse on smart cities increasingly reflects concerns about social and infrastructural (in-) justice, particularly within the governance and citizen-centered dimensions (Fig. 4). The role of data and digitalization in shaping urban life further complicates the justice landscape; In Helsinki, Dooley (2021) examines the city's bike-sharing program, where passive data collection allows transportation behavior to inform urban planning without requiring direct citizen engagement. While such models offer improved responsiveness, they raise concerns about algorithmic bias, limited transparency, and constrained public influence, especially in contexts where citizens have little control over how their data is used. However, despite the presence of progressive governance models, research warns that inclusion often remains superficial and symbolic rather than structural, and fails to meaningfully shift power dynamics in planning processes (Diaz et al., 2021). Mobility justice, although less frequently explored, emerges as a concern in smart city research in the case of Europe. It highlights how urban transportation systems often reflect and prolong social injustices. These inequities are especially evident in issues such as limited accessibility for people with disabilities, economic barriers to public transport, and the exclusion of marginalized populations from mobility planning. Insights from Stockholm, Sweden, reflect these points, revealing how smart mobility systems overlook the needs of older residents (Kåresdotter et al., 2022). Meanwhile, broader analyses across European cities link exclusionary patterns to gentrification, rising urban density, and housing shortages (see Kędra et al., 2023). Next, procedural justice emerges as the most frequently cited justice dimension in the European smart city context, underscoring the importance of participatory governance. Yet, many citizens continue to feel disempowered in planning processes, raising persistent concerns about whose voices are prioritized in shaping the city's digital and physical infrastructures (Rijshouwer et al., 2022). Without deliberate efforts to institutionalize inclusive participation, smart city initiatives risk reinforcing the very inequalities they aim to resolve.

Justice debates in Asia's smart city landscape are predominantly centered on mobility, governance, and, increasingly, environmental and people-focused dimensions (Fig. 4). Across the region, a range of cases illustrate the interplay between recognitional, procedural, distributional, and restorative justice concerns. For instance, in Indonesia, Asteria et al. (2020) explore smart city initiatives through a gender-equity lens, demonstrating how inclusive planning and participatory mechanisms enhance women's safety and improve access to public services. Similarly, in Taiwan, Huang et al. (2022) highlight the Smart Accessible Pedestrian Signal System (SAPSS), which supports visually impaired pedestrians. Both examples underscore the importance of procedural justice in ensuring that assistive technologies address the diverse needs of urban populations. In contrast, digital surveillance practices in the Israel-Palestine region reveal more troubling justice implications. Lahat and Nathansohn (2023) examine the deployment of CCTV systems in Tel Aviv, Haifa, West Jerusalem, and East Jerusalem, revealing how these technologies reinforce ethnic and political divisions between Jewish and Arab communities. This case highlights a critical need for restorative justice frameworks to address the embedded inequities perpetuated by smart city technologies.

Environmental justice has also become a growing area of concern in other parts of Asia. In Nagpur, India, Dhyani et al. (2018) document how urban sprawl and weak planning contribute to the degradation of wetlands and green spaces – impacts that disproportionately harm low-income communities. This case exemplifies distributional justice failures, as access to ecosystem services remains limited, often leaving marginalized populations to inhabit areas that are environmentally vulnerable and harmful to them. At the same time, infrastructural justice challenges persist across rapidly urbanizing Asian cities. Studies by Lung-Amam et al. (2021) and Aminah (2021) show how digital divide

limit civic participation and restrict access to public spaces, particularly for vulnerable groups. These disparities undermine Lefebvre's concept of the "right to the city," emphasizing the need for equitable access to digital and physical infrastructure (Lefebvre, 1967). In addition, infrastructural justice is also found in the Asian smart city context. Research highlights ongoing disparities in access to essential urban services such as digital connectivity, public transportation, and utilities (Pathak et al., 2021). These gaps not only deepen existing social and economic inequalities but also reveal the structural barriers that prevent marginalized communities from fully participating in urban life.

In Africa, research on smart cities remains limited, particularly from a justice-oriented perspective. Existing studies primarily address governance and urban living dimensions, with a focus on procedural and distributional justice (Fig. 4). However, most cases discuss justice in generic terms, without engaging deeply with specific justice frameworks or typologies. The absence of procedural inclusion in urban planning, alongside persistent inequalities in access to basic services, underscores a significant gap in justice-centered smart city research (Bello et al., 2024). While distributional disparities in water, electricity, transportation, and digital infrastructure are well documented, they are rarely framed explicitly through the lens of environmental or social justice.

Lastly, Oceania is represented by a single case only, which can be situated in the environment dimension of smart cities, with ecological justice type and recognitional justice themes. Though limited, this reflects concerns about Indigenous land rights, environmental ethics, and the inclusion of non-human actors in urban design (Tomitsch et al., 2021). However, the general lack of justice-focused smart city research from Oceania underscores the need to amplify region-specific voices and values in global discourse.

In short, in the Americas, infrastructural and social justice concerns in smart cities primarily revolve around governance and mobility, with a strong emphasis on procedural and restorative justice due to issues such as surveillance and exclusionary practices. In Europe, there is a more balanced integration of social, procedural, and recognitional justice, particularly within people-centered and inclusive governance frameworks. In Asia, smart city development highlights tensions between rapid urbanization and equitable access, especially regarding gender equity, environmental justice, and digital divides. In Africa, the discourse on justice remains underrepresented, revealing significant research and policy gaps, particularly in participatory governance and access to foundational services. In Oceania, justice themes are minimally present, though emerging ecological and Indigenous claims are beginning to influence environmental planning discussions. Therefore, it is evident that justice issues are deeply connected to smart city development, extending beyond digital development. These findings highlight the need to examine how vulnerable social groups are affected by the absence of justice. The next section will provide an overview of this issue, followed by a critical discussion in Section 5.2.

4.3. Vulnerable societal groups and the impacts of smart city initiatives

This section explores how smart city initiatives affect various societal groups, often exacerbating their vulnerability and marginalization. It also highlights the ethical considerations emphasized in the literature.

Of the 67 articles reviewed, 30 did not explicitly refer to specific social groups. Among the remaining 37 articles, low-income groups were the most commonly referenced, appearing in 16 studies (see Fig. 5a). These groups often face exclusion from decision-making processes and suffer from non-inclusive governance practices, limiting their influence on policies affecting their living conditions (Jeghers et al., 2024). Additionally, low-income segments of the population are more prone to be affected by issues related to the digital divide, which often stem from limited skills or a lack of accessible technological resources to use and shape digital services and environments. An illustrative example is provided by Masucci et al. (2021), who analyzed an educational youth program implemented in several schools in Pennsylvania, USA. The authors found that digital technologies used in urban spaces often fail to address the most pressing concerns among youths, particularly issues such as crime, drugs, and homelessness. Instead, youths tend to perceive the introduction of technologies as primarily benefiting population groups that are already better off. In fact, concerns related to distributional justice are commonly shared among the reviewed articles that examine justice issues affecting low-income segments in their case studies. Moreover, we found that low-income groups experience significant barriers in access to affordable housing and public transportation, for instance, exacerbating socio-economic inequalities (Levenda et al., 2020). This reflects justice concerns that align with the infrastructural justice type. However, although low-income groups experience infrastructural injustices, a major impeding factor appears to lie in governance-related factors. Governance and Administration have emerged as the primary sectoral focus concerning this segment of the population, with governance also being the most frequently highlighted smart city dimension. This suggests that the injustices faced by low-income groups stem from their exclusion from governance arrangements, with the consequences manifesting through infrastructure-related issues.

Ethnic minorities were discussed in six articles, with concerns over discriminatory surveillance, unequal access to employment opportunities, and a pronounced digital divide due to limited access to digital

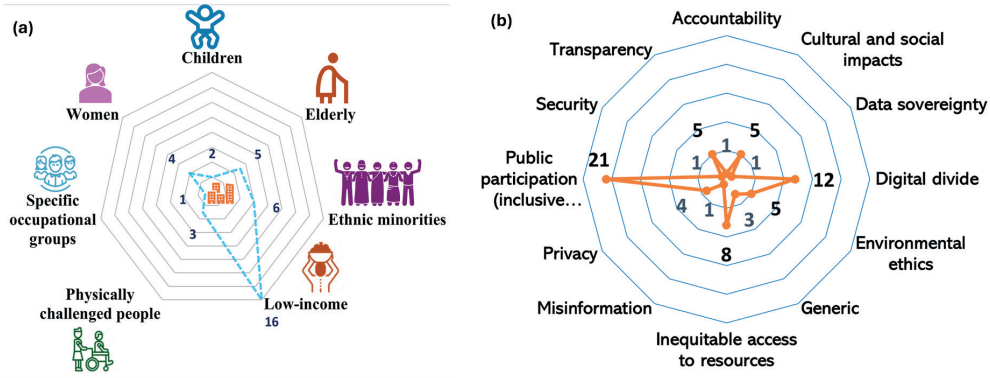

Fig. 5. (a) Vulnerable social groups excluded from smart city initiatives, illustrating disparities in inclusion and accessibility; (b) Ethical considerations related to societal groups in smart cities ((The icons are freely available at https://www.flaticon.com/).).

infrastructure and internet connectivity (Lahat & Nathansohn, 2023). Out of these six articles, three primarily addressed the social justice type. For instance, in their case study of Pune, India, Gandhi et al. (2021) show how "social-cultural and historical indicators are not considered an integral part" (p. 33) of the city's smart city development trajectory. This illustrates how centrally devised planning decisions can, by design, hinder ethnic minorities' efforts to achieve equitable access to resources and opportunities in smart cities. Instead, the interests of ethnic communities are often sidelined in favor of those of more influential and private actors, once again highlighting concerns related to the distributional justice dimension. Additionally, three of the six articles addressing ethnic minorities identified Telecommunications and Information Technology as the main sectoral focus. This suggests that the limited access ethnic minorities have to smart city services, and thus to opportunities for improving their quality of life, can partially be traced back to the uneven distribution and availability of these services compared to other segments of the population.

Five articles focused on elderly populations, highlighting their mobility challenges and difficulties adapting to rapidly advancing digital technologies, further isolating them from smart city services (Kåresdotter et al., 2022). Consequently, justice concerns related to the digital divide emerged as a common theme in this subset of reviewed articles. For example, in a case study of Helsinki, Finland; Santander, Spain; and the region of Flanders, Belgium, which participated in a pan-European project, Tupasela et al. (2023) found that decision makers and actors involved in implementing smart city projects struggle to understand and incorporate design decisions that address digital illiteracy among elderly populations. This again illustrates how, without a clear understanding of the specific needs and characteristics of certain groups, the benefits of smart city solutions can be unevenly distributed and tend to favor those who are more experienced in using digital services.

Women were the main social group in four reviewed articles, with discussions centered on safety concerns in public spaces and gender-biased employment disparities in the tech sector (Sontiwanich et al., 2022). Indeed, the recognitional justice dimension captures notions that are common amongst the subset of reviewed articles dealing with justice in smart cities regarding women. In several cases, the needs of women and their relative marginalization that is oftentimes rooted in societal norms, have not been recognized, resulting in limited representation in policymaking and urban planning processes that further restrict their ability to shape smart city development (see Rahman & Zhang, 2018). In an effort to alleviate these injustices, Asteria et al. (2020) promulgate that "various capacity building efforts for women must take place on multiple levels, with the integration and support from the collaboration of all stakeholders. This amounts to a paradigm shift in both the planning policies, regulation and management of smart cities" (p. 196).

Physically challenged individuals were highlighted in three articles, primarily with inadequate accessibility to public transportation and digital infrastructure. The reliance on assistive technologies also raises concerns over privacy and data security, as these tools collect sensitive personal data (see Pathak et al., 2021). Here, the aspect of recognitional justice plays a major role. Without taking into account the needs of physically challenged individuals in the design of smart city solutions, these individuals are at risk of being further marginalized. Conversely, when designed with consideration for their needs, smart city solutions can help them access urban services that were previously unavailable, for example by making it easier to navigate urban environments (Huang et al., 2022). Our findings underscore both the importance of the Infrastructural justice type and the Mobility smart city dimension for the quality of life of physically challenged segments of the population.

Two articles explicitly dealt with children in the context of smart cities, attending to educational schemes intended to build digital skills and capacities (Lim et al., 2022) and sustainability concerns for future generations (Mayaud et al., 2019). These two studies are primarily concerned with potential injustices arising from distributional issues. Due to their vulnerability and dependence on caretakers, children are often disproportionately exposed to the adverse effects of smart city projects, such as displacement or pollution.

Only one article addressed specific occupational groups, emphasizing the importance of public spaces for certain professions (Aminah, 2021). The content analysis also found that, over time, the emphasis on societal groups in smart city research has increased, as illustrated in Fig. A1c (e-component). However, certain segments of society continue to be insufficiently included.

Beyond these group-specific disparities, our analysis of ethical considerations (see Fig. 5b) revealed that public participation and inclusive governance – crucial for mitigating these inequalities – were referenced as major ethical concerns in 21 studies. The digital divide was explicitly mentioned in 12 articles, underscoring its disproportionate impact on marginalized communities. Inequitable access to resources was raised in eight articles, while privacy concerns were highlighted in four studies, particularly concerning physically-challenged individuals relying on assistive technologies. Additionally, transparency, cultural and social impacts, and environmental ethics were discussed in five studies each, emphasizing the complex ethical landscape surrounding smart city development. These findings suggest that, despite growing concerns over justice in smart cities, the inclusion of vulnerable societal groups remains insufficiently highlighted in scholarly discourse. However, evolving trends indicate an increasing emphasis on public participation and citizen engagement, shifting from a peripheral concern to a central theme in shaping future smart city governance (see Fig. A1d in the e-component). The following section presents a critical perspective on addressing the needs of vulnerable societal groups in smart cities by positioning justice as a central theme, and explores how it can be integrated into governance structures to promote more equitable outcomes.

5. Discussion: the role of governance for a 'just' smart city development

As cities become more data-driven, the emphasis on governance reflects the need for robust policy frameworks, regulatory mechanisms, and institutional accountability to ensure smart city technologies' ethical and equitable implementation (see Beckers & Mora, 2025; Mora et al., 2025). Our analysis seconds and further highlights the importance of governance for successfully implementing smart city projects and their solutions. However, in doing so, we also expose power imbalances in quadruple helix collaborations. In fact, smart city "governance--beyond-the-state" (Swyngedouw, 2005, p. 1991) appears to be often shaped by the interests of powerful private actors who may hold more influence over decision making than citizens, private non-profit organizations, and even local or national governments. For instance, Sontiwanich et al. (2022) criticized the smart city development in Phuket, Thailand, for being designed primarily to serve urban elites. Additionally, resistance from powerful actors can hinder the adoption of more democratic planning approaches and restrict access to public spaces and institutions, such as cultural facilities (Diaz et al., 2021). Power imbalances are particularly evident in infrastructure- and technology-centric projects, which tend to prioritize economic interests and those of more influential actors. For instance, in a case study on Turku, Finland, Träskman (2022) found that the city initially developed as a smart city based on industry-defined indicators. As a result, Turku was considered "smart" primarily from an industry perspective, which significantly influenced the direction of its smart city initiatives. The focus remained on ICT infrastructure, which primarily benefited the industry, reducing residents to passive data nodes rather than active participants in decision-making. Such a bias raises ethical concerns about governance and accountability, particularly in how digital infrastructure is implemented to manage participatory processes equitably. The case of Turku illustrates how data tracing can create uneven value distribution, reinforcing power imbalances and limiting the inclusivity of smart city development at the expense of city users other than private actors, and

citizens in particular. The focus on infrastructure- and technology-driven projects is also evident in Baltimore, USA, where insights from lower-income areas facing basic service shortages, informality, and socio-political instability are often marginalized, reinforcing global knowledge asymmetries in smart city discourse (Lung-Amam et al., 2021). This case highlights the digital divide and the ethical imperative of ensuring equitable resource access. It underscores how technological accessibility – or its absence – can shape urban inequalities, emphasizing the large-scale impact of the digital divide on marginalized communities. Hence, our study highlights a potential disconnect between the theoretical foundations of smart city governance, which promote collaboration through quadruple helix models, and the reality in practice, where effective mechanisms to support such collaboration and enable just smart city development appear to be often lacking. Moreover, we emphasize that even when smart city governance is guided by principles of collaboration and shared decision making, it does not guarantee just outcomes. In fact, our analysis suggests that governance structures lacking equity and fairness can actively contribute to the emergence and reinforcement of injustice. The lack of justice-focused smart city research can limit the ability of governance approaches to address socio-economic disparities, particularly in cities where informal settlements, low-income populations, and climate vulnerabilities are prevalent (Miklian & Hoelscher, 2017). In their current form, smart city developments often risk further marginalizing already marginalized communities that live in poverty and rely on informal economies, accelerating gentrification and forced displacement. This, in turn, can fragment or even dismantle established communities, eroding social capital and weakening support networks. Such developments also raise the ethical consideration of inequitable access to resources, as shown by Bandauko and Nutifafa Arku (2023) in a multicase study of smart city projects in Nairobi (Kenya), Johannesburg (South Africa), Lagos (Nigeria), Kigali (Rwanda) and Casablanca (Morocco). Beyond social consequences, such exclusionary disruptions are likely to also have economic implications and disproportionately burden the poor (Praharaj, 2021). For instance, the high costs of "smartified" essential services like water and sanitation may drive low-income groups to the city's peripheries. As a result, displaced residents may face longer, more challenging, or even unfeasible commutes to their places of work, reducing employment opportunities and deepening financial instability (Jeghers et al., 2024). Other dominant ethical considerations in smart city research, particularly around algorithmic bias, data sovereignty, and digital exclusion, can also have direct implications for urban justice (Ziosi et al., 2023). The increasing reliance on predictive analytics and AI-driven urban governance raises concerns about transparency, accountability, and the reinforcement of socio-economic disparities in areas such as mobility, housing, and resource allocation (Sawhney, 2023).

As a result, we argue that dominant scholarly debates on smart city governance should adopt a more holistic perspective, one that acknowledges smart city development as a multi-scalar process that cannot be effectively addressed at any single level of governance. This implies the need to synthesize "political structures, regulatory frameworks, and decision-making processes at multiple administrative levels" (Beckers & Mora, 2025, p. 4), as well as the need for strategies and approaches beyond the smart city aegis that complement one another. While we argue that centering justice at the heart of the smart city concept is inevitable, we also stress that smart cities alone are insufficient to address grand societal challenges such as climate change or poverty. Instead, the smart city concept should be considered a piece of the puzzle in the broader pursuit of justice, aligned with the creation of responsible, inclusive, and equitable environments for all social groups, both within and beyond urban areas. Expecting that technologies employed in smart cities, as just as their design and implementation may be, alone can address grand societal challenges such as climate change or poverty reflects a form of "techno-utopianism" (Bina et al., 2020, p. 12), which may lead to overly optimistic expectations about the impact of technologies, potentially resulting in delayed action or even inaction, resting in an unsolicited "hope for better days to come" (Gramstad et al., 2014, p. 12).

During the course of our review, we identified several instances which provide grounds for our claims and illustrate how a more holistic interpretation of smart city governance has positively impacted marginalized communities and led to greater inclusion. For instance, Sawhney (2023), in his case study on urban mobility and AI in Amsterdam, Netherlands, emphasizes the crucial role of regulatory frameworks and a form of *governmentality* (Rose et al., 2006) that not only enhances regulatory mechanisms but also promotes transparency, accountability, and the protection and empowerment of citizens' rights. Indeed, when such notions of inclusivity are core principles – not just an afterthought – smart city development can benefit vulnerable populations (Bradshaw & Kitchin, 2022); Rather than solely rectifying existing disparities, our analysis suggests that justice also involves preempting inequality through proactive urban planning. This is evident in transit-oriented development efforts in Budapest, Hungary, which seek to create efficient urban environments while ensuring equitable access to essential services (Suryawan et al., 2024). Inclusivity as a planning paradigm was also embraced in Montgomery and Chattanooga, USA, where smart city projects have improved urban spaces, particularly aiding ethnic minorities, including African-American communities (Sucupira Furtado et al., 2023). Likewise, implementing smart city solutions through a bottom-up approach can benefit low-income households. In Nairobi, Kenya, for example, this approach has led to increased trust in public authorities (Bandauko & Nutifafa Arku, 2023). Further examples of community-based approaches were observed in Ontario, Canada (Popham et al., 2020) and Roanoke, USA (Lim et al., 2022). In these cases, participants anticipated that integrating feedback mechanisms would help develop a robust, iteratively refined set of policies to address and overcome digital inequalities. City residents can also be trained and educated not only to raise awareness of smart city projects but also to actively participate in them, as demonstrated in several cities in Korea. Participation can be further encouraged through incentives, such as offering individuals roles of authority, while ensuring these opportunities are clearly communicated (Choo et al., 2023). Jurado-Zambrano et al. (2023) also highlight that linking local smart city initiatives to broader, global smart city development paradigms – such as those proposed by NGOs (see Beckers et al., 2022, 2023) or academics (see Mora et al., 2025) – can be beneficial, provided they are adapted to local context conditions. Furthermore, our analysis revealed that it is potentially important to consider a multitude of justice dimensions for smart city initiatives, where reviewed articles particularly stress a combination of procdeural, distributional and recognitional justice dimensions.

Nonetheless, many of the best practice examples and their impacts analyzed in our review are relative. While they may have improved living conditions for marginalized communities, they often disproportionately benefit segments of the population that were already better off before the introduction of smart city solutions. This can further widen existing inequalities rather than bridging them. From an ethical standpoint, this situation raises concerns about equity and justice in urban development, as smart cities risk perpetuating the status quo by benefiting those already advantaged. Hence, with these insights, we contribute to the evolving discourse outlined in the Introduction section, which advocates for viewing smart cities as the product of continuous sociotechnical processes rather than merely as techno-centric interventions.

6. Conclusion

6.1. Summary of principal findings

This systematic literature review presents a structured and cohesive framework for addressing the complex justice-related challenges in

smart cities. It offers valuable evidence that enhances the broader understanding of justice themes within smart city research. Our analysis highlights important gaps and new trends while thoroughly examining justice considerations in the conversation around smart cities.

Infrastructural justice was the most frequently discussed type, highlighting disparities in access to basic urban infrastructure in marginalized communities. Social justice followed, with a focus on (the lack of) participatory platforms addressing inequality. Mobility justice underscored inequities in urban transport, particularly for low-income and disabled populations, emphasizing the need for inclusive solutions. Environmental and ecological justice were the least explored, despite their critical role in sustainability.

In terms of justice dimensions, procedural justice was the most frequently discussed, highlighting the importance of inclusive decision-making in smart cities. Many studies pointed to challenges like limited public awareness and tokenistic participation, stressing the need for grassroots involvement. Distributional justice focused on disparities in resource allocation, particularly in fast-growing, unplanned cities where vulnerable groups face the greatest inequities. Recognitional justice addresses the marginalization of underrepresented groups, including women and individuals with disabilities, signaling the need for a shift toward more inclusive urban planning. Restorative justice was the least explored, focusing on reconciliation efforts in post-conflict or economically restructured cities, highlighting the need for justice-driven urban transformation.

In addition to these descriptive insights, our analysis draws attention to several cross-cutting dynamics that call for a more intersectional and systemic understanding of justice in smart city contexts. First, the intersection of justice themes and sectoral focus reveals that sectors such as transportation and telecommunications, which are often approached from a techno-centric perspective, can reproduce social exclusion if not implemented with attention to procedural and recognitional justice. Surveillance technologies, for instance, can exacerbate racial and ethnic tensions, while assistive mobility tools, if properly governed, can significantly enhance accessibility for disabled individuals.

Second, vulnerability is not monolithic. Different societal groups, such as low-income populations, ethnic minorities, women, elderly individuals, and children, face unique and overlapping forms of marginalization. Their exclusion from smart city benefits is often tied to multiple justice dimensions simultaneously. For example, elderly populations are not only impacted by the digital divide (distributional justice) but also by the lack of design consideration (recognitional justice) and weak means of engagement (procedural justice).

Third, technological advancement is not inherently progressive. Several studies highlight the risk of "techno-utopianism," where the mere presence of smart infrastructure is assumed to deliver just outcomes. Our findings show that without intentional design, implementation, and oversight grounded in justice principles, smart technologies can deepen existing inequalities. This is particularly evident in the displacement of low-income groups through infrastructure-led gentrification and in the exclusion of digitally illiterate populations.

6.2. Theoretical contributions

With this study, we intend to contribute to advancing smart city scholarship by offering a systematic examination of justice as a central, rather than peripheral, element in smart city development. While the importance of inclusive governance approaches is increasingly acknowledged in existing literature, our contribution lies in deepening and structuring this perspective through a justice-oriented lens.

In detail, we first introduce a structured analytical framework that distinguishes between justice types and justice dimensions. This distinction enables a more precise understanding of how justice concerns manifest in smart city contexts. It allows for clearer comparisons across cases and reveals how different forms of injustice, such as infrastructural, social, or recognitional, intersect with specific urban sectors and technologies.

Second, our study contributes a more critical perspective by showing how governance arrangements often reinforce exclusion, particularly when dominated by private interests at the expense of civil society and marginalized groups. At the same time, we identify governance as an area where meaningful change is possible, particularly when communities and local actors are empowered to shape decisions and allocate resources.

Third, our findings expose a persistent gap between theoretical, idealistic debates and practical realities. While academic and policy models often promote collaborative, multi-actor approaches to governance, smart city initiatives frequently marginalize vulnerable populations and reinforce power imbalances. By highlighting this discrepancy, our study underscores the importance of aligning governance practices with justice-oriented principles in order to achieve meaningful inclusion.

Fourth, we argue that justice in smart cities should not be treated as a corrective measure applied after systems are in place. Rather, justice must be integrated from the beginning as a guiding principle in the design, planning, and implementation of smart city initiatives. This requires a shift from viewing justice as a static end goal to understanding it as a continuous and dynamic process that shapes decisions at every stage of urban development.

Finally, by drawing on a wide range of empirical cases, our study brings intersectionality into the center of smart city theory. Justice issues rarely affect people in isolation. They are shaped by overlapping forms of vulnerability related to various factors, such as income, gender, age, ability, and ethnicity, which may be even further exacerbated by grand societal challenges such as climate change or poverty. Our findings demonstrate how these elements interact with governance structures to either amplify or mitigate exclusion. As a result, we argue for a more nuanced and intersectional approach to theorizing justice in smart cities.

6.3. Practical contributions

This study presents four key practical contributions to the development of smart cities through a justice-driven strategy. First, it seeks to position justice as a central element – rather than an afterthought – in smart city development. This could help in shaping the mindset of practitioners to prioritize notions of justice from the outset. Second, it emphasizes the importance of context-sensitive frameworks that adapt policies to local socioeconomic conditions, ensuring they are both relevant and effective. Third, it advocates for inclusive governance, ensuring that historically excluded groups have a meaningful voice in decision-making processes. Finally, it underscores the necessity of digital equity, promoting fair access to urban technologies for all stakeholders, thereby fostering a more just and sustainable smart city ecosystem.

6.4. Limitations and further research

Despite implementing rigorous control and quality measures throughout the review process, we acknowledge that certain degrees of subjectiveness could exist in identifying and analyzing various justice types and dimensions. Moreover, although no geographic limitations were imposed on article selection, the final sample reviewed is skewed toward case studies primarily representing experiences from North America, Asia, and Europe. We encourage future research to replicate our study, potentially adopting alternative interpretations of justice and a more focused examination of specific geographic regions.

Generally, we call for future research to include equity-driven frameworks in policy models and technical breakthroughs in order to align smart city development with global justice imperatives. Without a deliberate shift toward justice-centered urban solutions, smart city

initiatives risk deepening existing disparities, particularly in access to essential services, digital infrastructure, and public participation. Justice-oriented approaches must prioritize inclusion over efficiency and optimization to ensure that smart city programs do not unintentionally reinforce socioeconomic and environmental inequalities. This shift must also explicitly address the needs of non-human entities and ecosystems. Importantly, we emphasize that future smart city research should consider historical trajectories – reflecting on past injustices, environmental and ecological disruptions – to inform more just and resilient solutions. Failure to adopt such a perspective would limit the transformative potential of smart cities, preventing them from fostering sustainable and equitable urban futures. In addition, research gaps remain in explicitly analyzing the experiences of marginalized communities. These include the groups we examined in this study, as well as additional communities – such as immigrants, refugees, and individuals experiencing homelessness – who are highly vulnerable and often receive minimal recognition due to their residency status. Closing this gap is essential to provide policymakers with critical insights into who is being excluded, the nature of these disparities, and how inclusive smart city policies can be designed to bridge existing divides rather than widen them.

Our line of argumentation naturally leads to a critical question: How can we outline a path forward for developing just governance principles that are well suited to addressing the needs of vulnerable societal groups in smart city development? We encourage future research to delve deeper into the development of actionable governance frameworks that facilitate the seamless and effective integration of justice principles into smart city development. Rather than being perceived as obstacles or burdens, these principles should be embedded in ways that position them as accelerators and catalysts of urban digital innovation. Future smart city studies must prioritize these goals – let us strive to make cities not only smart, but also just and sustainable.

CRediT authorship contribution statement

Md. Nazmul Haque: Conceptualization, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Dominik Beckers:** Data curation, Investigation, Writing – original draft, Writing – review & editing. **Emilio Costales:** Data curation, Writing – original draft, Writing – review & editing. **Samar Aad:** Data curation, Writing – original draft. **Ayyoob Sharifi:** Conceptualization, Data curation, Writing – original draft, Writing – review & editing, Methodology. **Luca Mora:** Conceptualization, Data curation.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used Grammarly to check the grammar, punctuation, and clarity. After using this tool, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techsoc.2025.103050.

Data availability

Data will be made available on request.

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Overcoming the Smart City Governance Challenge: An Innovation Management Perspective

Dominik Beckers[a,b] and Luca Mora [a,b,c*]

[a]Tallinn University of Technology, Academy of Architecture and Urban Studies, Estonia; [b]Tallinn University of Technology, FinEst Centre for Smart Cities, Estonia; [c]Edinburgh Napier University, The Business School, Scotland

ABSTRACT

This commentary explores the potential of strengthening smart city development (SCD) governance theory through a more meaningful integration of innovation management studies. We highlight the limited theoretical framework in SCD governance and show how theoretical stimuli from innovation management can address key governance challenges affecting SCD. Our focus encompasses several governance challenges that we use as exemplary cases: conceptualizing SCD, strategizing citywide SCD efforts, introducing monitoring methods and indicators for SCD projects, intermediating among stakeholders, and managing multi-level governance dynamics. The primary goal of our commentary is to advocate for increased multidisciplinary research in the SCD field, emphasizing the accelerated knowledge accumulation achievable by linking it with the more established field of innovation management studies. We conclude that innovation management offers valuable insights for advancing SCD governance theories. This commentary initiates a dialogue on the necessity of cross-disciplinary research in the smart city domain, which is expected to benefit both academics and practitioners.

KEYWORDS

urban innovation; innovation management; smart city projects; governance; theory building

Introduction

Interpreted as an answer to the socioeconomic and environmental sustainability challenges faced by urban environments worldwide, smart city development (SCD)[1] calls for "new ways of organizing city functions and urban life" (Ruohomaa et al., 2019: 6). By introducing digital technologies to boost sustainable urban development, SCD projects can trigger urban innovation processes (Bjørner, 2021). Their objective is to alter unsustainable urban development models by fixing the inefficiencies of social-technical systems for urban service delivery—for example, services related to transport, energy, waste management, healthcare, safety and security, housing, and education systems (Mora et al., 2021). SCD projects can be developed and deployed to rearrange the functioning of any urban socio-technical system. However, they cannot be

CONTACT Luca Mora L.Mora@napier.ac.uk Edinburgh Napier University, 219 Colinton Road, Edinburgh EH14 1DJ

governed in isolation; city-level coordination is required to realize cross-project synergies and ensure that the complexities of systemic urban challenges are addressed through a portfolio of complementary initiatives (De Sanctis et al., 2022). What ensures this level of coordination are governance mechanisms that create an organic whole, by establishing how different societal actors (from individual citizens to public and private organizations) should interact and collaborate in SCD projects (Garcia Alonso and Castro, 2016). Tasks, duties, and responsibilities are distributed across a wide range of stakeholders, leading to what Swyngedouw (2005) defines as "governance-beyond-the-state."

Effective governance frameworks can facilitate cross-sector innovation efforts (Torfing and Triantafillou, 2016) and improve the quality of life of citizens by integrating new technologies in public infrastructure to achieve community goals (Micozzi and Yigitcanlar, 2022). For example, SCD promises improvements in city services, increased social participation, better communication, enhanced education, and reduced digital inequalities (Viale Pereira and Schuch de Azambuja, 2021). However, the assemblage and functioning of governance approaches to SCD has not been sufficiently explored in scholarly research (Ruohomaa et al., 2019). Current theoretical formulations fall short in both explaining and guiding the management of SCD projects, resulting in a gap in evidence-based understanding among societal actors (Mora et al., 2020). Traditional urban governance models often struggle to keep up with the complex demands of digital transformations in urban settings. Research remains limited on how governance structures need to adapt to support SCD effectively (Razaghi and Finger, 2018; Ruhlandt, 2018). Scholars such as Ooms et al. (2020) emphasize that SCD projects require flexible, evolving governance arrangements to match their dynamic timelines. However, further investigation is needed to understand how these adaptable structures can be generalized across different SCD contexts (Chaffin et al., 2014).

In light of this inadequately developed theoretical background, numerous SCD projects launched by municipal governments worldwide have demonstrated issues with suboptimal planning and execution (Lee et al., 2014). This is a global challenge that has gained attention not only in academic circles but also in international policy debates. The United Nations, for example, recognizing the criticality of this challenge, have issued an urgent call to action to enhance research on SCD governance (UN-Habitat, 2022, 2023).

We respond to this call by addressing the following question: how can innovation theory help overcome SCD governance challenges? In this commentary, we show how the weak theoretical apparatus supporting SCD governance practice could be strengthened by invigorating the promising connection between innovation management studies and SCD research. Our perspective builds on the claim that, as of today, this cross-disciplinary connection has been underutilized; relevant theories and conceptual stimuli from innovation studies have been insufficiently leveraged to advance the SCD debate, and the studies that have built on this symbiosis have shown ample potential for theory development that has yet to be fully exploited (Dameri and Ricciardi, 2015; Maye, 2019; Mora et al., 2023). For instance, Karimikia et al. (2022) have applied boundary spanning theory to explore the complexity of governing smart city units—organizations or agencies responsible for coordinating a city's SCD projects. Similarly, Lee

(2020) has analyzed these organizations through the lens of living lab theory. Paskaleva (2011) used open innovation theory to study European trends in SCD projects, highlighting an emerging approach among practitioners that effectively connects technology with people, urban spaces, and other cities while facilitating the sharing of visions, knowledge, skills, and strategies for urban service and policy design. Moreover, Paskaleva stresses the need for clear theoretical frameworks, principles, and strategic agendas to unify these elements effectively. Nilssen (2019: 98) contributes a "typology of smart city initiatives" based on the extent and types of innovations involved, while Costales (2022) and Leitheiser and Follmann (2020) draw on social innovation theory to better understand the socioeconomic dimensions of SCD. Together, these case studies demonstrate the value of examining SCD governance through an innovation management perspective. This approach offers novel insights and supports theory development at the intersection of urban studies and innovation management, where a new field of inquiry is emerging, specifically focused on the interplay between urban settings and innovation (Nilssen, 2019).

Similarly, several scholars have shown that insights from innovation management can enhance our understanding of economic (Nogueira et al., 2019), environmental (Loorbach and Rotmans, 2010), and social (Ardill and Lemes De Oliveira, 2018) dynamics. These dynamics are central to SCD, which, in turn, influence their evolution (Bolívar and Meijer, 2016; Caputo et al., 2019). This intersection offers significant potential for advancing theory-building in SCD governance.

Aligning with scholars like Meijer and Bolívar (2016) and Pereira et al. (2018), we argue that governance arrangements are essential in guiding transformative economic, environmental, and social dynamics. These arrangements must be adaptable and evolve over time to address changing needs, clarify governance objectives, navigate complex contexts, and manage uncertainties in implementation (Rijke et al., 2012). In this commentary, we highlight the potential of innovation management studies to support theoretical advancements in SCD governance research. Table 1 provides examples of how specific innovation management theories can be connected to smart city governance challenges, with further details in the following sections.

The importance of addressing SCD governance and the challenges listed in Table 1 is strongly emphasized in two recent United Nations (UN) reports: *Global Review of Smart City Governance Practices* (UN-Habitat, 2022) and *Managing Smart City Governance: A Playbook for Local and Regional Governments* (UN-Habitat, 2023). These reports identify critical issues in key governance areas of SCD projects. We do not aim to cover all governance challenges comprehensively, but rather to present examples that illustrate the scope of significant issues identified in these UN reports. These examples serve to reveal the often-overlooked potential of innovation management studies to contribute to advancing debates on smart city governance.

It is important to clarify that our objective is not to present an exhaustive list of all theoretical concepts from innovation management studies applicable to SCD governance research. Such an endeavor exceeds our current scope. Instead, we concentrate on showcasing a selection of theories from innovation management that are particularly promising for enriching SCD governance research. These theories are considered fundamental in the innovation management field due to their ability to provide a profound comprehension of the intricacies of managing innovation. Although these theories may have

Table 1. Matching: addressing smart city governance challenges with innovation management theories

Smart City Studies		Innovation Management Studies	
Governance Challenges	Description	Relevant Theories	References
Conceptualization	• Definitional problem caused by terminological confusion • City-level focus • Smart city transformations interpreted as one-size-fits-all applications of technological solutions	*Social-technical transitions*	(Geels and Schot, 2007; Leonard-Barton, 1988)
		Social innovation	(Ardill and Lemes De Oliveira, 2018; Costales, 2022)
		Sensemaking	(Hübel, 2022; Pizzo et al., 2021)
		Boundary objects	(Mäenpää et al., 2016; Zhuo and Chen, 2023)
Strategy	• The need for citywide coordination of smart city projects and the creation of overarching smart city strategies	*Strategic orientation and flexibility*	(Cheng and Huizingh, 2014; Gatignon and Xuereb, 1997; McKee et al., 1989)
		Technology roadmapping	(Lee et al., 2011; Martin and Daim, 2012; Phaal et al., 2004)
		Open strategy	(Chesbrough and Appleyard, 2007; Hautz et al., 2017)
Monitoring	• Universal performance measurement dimensions that tend to overlook local context conditions • Static and formative key performance indicators that are backward-looking and overlook ongoing monitoring	*Innovation indicators*	(Dziallas and Blind, 2019; Truffer et al., 2017)
		Developmental evaluation	(Lam and Shulha, 2015; Patton, 2016)
Intermediation	• Incomplete understanding of smart city units, their organizational design, and their routines	*Innovation intermediaries*	(Howells, 2006; Kanda et al., 2020; Rossi et al., 2022; Sovacool et al., 2020; van Lente et al., 2003)
		Living labs	(Alam and Porras, 2018; Bulkeley et al., 2016)
		Transformational and charismatic leadership	(Aarons and Sommerfeld, 2012; Paulsen et al., 2009)
Multilevel Governance	• Coordination of political structures, regulatory frameworks, and decision-making processes at multiple administrative levels	*Boundary management*	(Capurro et al., 2021; Garzella et al., 2021; He and Berry, 2022)
		Scaling	(De Roo et al., 2019; Schut et al., 2020)

originated from broader disciplines, their refinement and implementation in innovation management have yielded significant relevance and insights.

To align theoretical stimuli with governance challenges, we conducted a review of theories and concepts from the field of innovation management. From this extensive array, we chose those theories that we believe to be exceptionally apt for contributing to SCD governance research. Our selection process was guided by evaluations and personal interpretations of each theory's potential to enhance SCD governance studies. This process was also informed by academic discourses in innovation management literature, particularly where these theories have been effectively employed.

The structure of our commentary is as follows. Following this introduction, we outline the five governance challenges that we selected, drawing on pertinent literature in the SCD domain. We then delve into each challenge, which we examine through the lens of theoretical developments from innovation management studies. The commentary culminates with a concluding section that encapsulates our main arguments and discusses

the possible impact of our perspective on the SCD knowledge field, emphasizing the necessity for more cross-disciplinary research.

Smart City Development Research Meets Innovation Studies

Conceptualization Challenge

Approaching SCD governance requires a clearer, more inclusive, and shared understanding of the SCD concept. This statement builds on a threefold critique. First, when dealing with the smart city term, there is a definitional problem that is caused by "terminological confusion" (Dameri and Cocchia, 2013: 5). Instead of agreeing on a shared definition, scholars and practitioners have been referring to SCD projects by using a multitude of different expressions—such as sustainable, green, smarter, digital, intelligent, and ubiquitous—in an interchangeable way (Samarakkody et al., 2019), without considering that these terms are interrelated but carry different meanings (Mora and Deakin, 2019). This lack of consensus (Gil-Garcia et al., 2015) has resulted in an oftentimes-attested misinterpretation and use of the SCD concept that has raised concerns questioning the effectiveness of the concept altogether (Anthopoulos et al., 2019). Second, by explicitly focusing on the city-level, the SCD term neglects the multitude of SCD projects that involve lower or higher levels of application, such as regions, neighborhoods, buildings, or specific infrastructure components (Walters, 2011). Third, many interpretations tend to describe SCD transformations as the outcome of one-size-fits-all applications of technological solutions rather than the result of social-technical innovation processes that are context-dependent (Meijer and Thaens, 2018). Interpretations based on technological solutionism have been critiqued for fostering a utopian, technology-deterministic view that primarily benefits technology providers, rather than effectively tackling the complexities of urban development (Mora and Deakin, 2019).

From an innovation management perspective, this conceptualization challenge can be comprehended as a form of *sensehiding*: a process of "distorting and manipulating images through holding back particular aspects or cues" (Horbach et al., 2018: 417). Scholars tend "to be subjective and follow personal trajectories in isolation from other researchers" (Mora et al., 2017: 20), and their interpretations only acknowledge aspects of the SCD concept that suit their own research objectives, while deliberately or unconsciously omitting other relevant features. For instance, current literature emphasizes that SCD projects cannot be solely interpreted as a means of generating technological change (Albino et al., 2015). But techno-driven SCD discourses persist (Guma and Monstadt, 2021), neglecting the social-technical implications of digital transformations that innovation studies highlight. Building on theories at the interface between innovation management and social-technical transition studies, SCD projects could be interpreted as social-technical transformation processes that originate from reconfigurations of technological systems as well as normative, cognitive, regulatory, and market mechanisms (Hillman et al., 2011).

Linking the conceptualization of SCD projects to social-technical systems theory enables a more pragmatic and holistic understanding, anchoring these projects within the complex interplay of technology, social structures, and human behavior (Mora et al., 2020). Additionally, it helps transcend their conventional portrayal at just the

city level. Social-technical transitions, as defined in innovation studies, involve extensive socio-spatial changes that span across administrative levels, both within and beyond the boundaries of a city (Späth and Rohracher, 2012). Adopting a social-technical perspective allows for a deeper understanding of the varied scales at which SCD projects operate. This perspective supports a shift from the narrower term smart *cities* to broader, more inclusive concepts like smart *places* and smart *territories*, which have recently begun to emerge at the intersection of innovation management and smart city governance literature (Gorelova et al., 2024; Navío-Marco et al., 2020). These terms offer a more inclusive and realistic interpretation than the traditional notion of smart cities.

Observing SCD through a social-technical lens reveals social innovation as a key catalyst and outcome of urban digital innovation (Ardill and Lemes De Oliveira, 2018). Within this theoretical framework, social innovation acts as a dynamic process that reshapes societal norms, values, and behaviors to offer innovative solutions for pressing social challenges. This transformative process results in lasting changes in social systems, emphasizing the importance of collaboration, inclusivity, and trust (Kim et al., 2021; Moore et al., 2015; Westley et al., 2014). Moreover, the sustainability objectives inherent to SCD projects highlight the complex interplay between social transformation and economic growth, driven by technological advances. Social innovation strategically addresses this interconnectedness (Costales, 2022).

Innovation theory could also help embrace a broader conceptualization of SCD, by building on the notion of *making process* (Geels and Schot, 2007). This notion posits that technological innovation emerges from ongoing interactions between a technology and its surrounding environment (Leonard-Barton, 1988). As a result of these interactions, through SCD projects, digital solutions and urban contexts engage in a mutual adaptation process, where each continuously adjusts to the other.

Zuzul's (2019) research offers relevant insights into how sensehiding can harm SCD. By analyzing two SCD projects, Zuzul observed that project partners embraced varying interpretations of the SCD concept. Their disagreement generated "concept ambiguity" (739), which in turn triggered "process ambiguity" (739). These divergent understandings of how to manage SCD projects resulted in both partnerships failing to achieve their goals, primarily due to the lack of a shared definition of the SCD concept from the outset.

To counteract this conceptual ambiguity, we invite SCD scholars to integrate sensemaking theory into academic discussions. Unlike sensehiding, sensemaking involves a collaborative process where project partners converge on interpretations and applications of contentious concepts (Horbach et al., 2018; Hübel, 2022). For example, Seligman (2006) effectively employs sensemaking theory to dissect technology adoption models, revealing the underlying mental frameworks and how they influence adoption practices. Applying this analytical process in SCD research could illuminate the interplay between mental models and SCD project execution, an area that remains underexplored.

Particularly useful in the SCD context is the retrospective nature of sensemaking. Past experiences and perceptions shape initial mental representations of concepts and boundary objects, linking diverse social worlds (Weick, 1995). By positioning this retrospective view in the SCD domain, these mental models should encompass the array of existing interpretations, forming a basis for an evidence-driven sensemaking process. Connecting these interpretations can help establish a unifying understanding of the SCD concept,

which is vital for aligning academic discourses with practical applications and preventing both concept and process ambiguities (Pizzo et al., 2021).

Finally, research on boundary objects is central to sensemaking theory (Mele et al., 2019) and offers an additional lens from innovation theory for examining project-level conceptualization issues. As innovation scholars explain, "boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use and become strongly structured in individual-site use" (Star and Griesemer, 1989: 393). In SCD, the conceptualization of an SCD project itself can be seen as a boundary object, whose objective is to facilitate alignment among project partners. This alignment extends to other project elements like plans, objectives, and strategic orientations.

Strategy Challenge

The importance of strategizing citywide coordination in smart city initiatives is a critical yet underexplored area in the literature (Pivar, 2019). While many studies encourage local governments to develop digital innovation strategies that involve various societal actors, there is a lack of guidance for creating comprehensive strategies that systematically address SCD projects (Ojo et al., 2015). These frameworks should be regarded as adaptable frameworks, allowing cities to develop approaches that align with their distinct characteristics and requirements. This gap in research leads to a situation in which practical implementation surpasses theoretical generalizations in academic discourses (Lee et al., 2014). However, digital innovation strategies often are too theoretical, based solely on literature reviews without considering practical application, or they focus narrowly on technological and architectural aspects, neglecting social and environmental impacts (Nam and Pardo, 2011; Zygiaris, 2013).

Innovation scholars emphasize that any attempt to orchestrate a portfolio of innovation projects in an organization requires a strategic orientation (Tutar et al., 2015). This perspective is echoed in the SCD domain, where digital innovation strategies are crucial for unified city-level development, preventing the fragmentation of projects and resources (Komninos et al., 2019; Mora et al., 2019). The importance of introducing citywide strategic coordination and orchestration is particularly evident in the work by Mora et al. (2020). Building on transition theory (Geels and Schot, 2007), the authors show that urban digital transformation efforts tend to generate from a multitude of interrelated projects that cannot be implemented in isolation from one another.

For advancing digital innovation strategies for urban areas, SCD can benefit from insights in technology strategy and technology transitions (see Phaal et al., 2004), including technology roadmapping (TRM) theories. These theories, grounded in literature on strategic orientation and flexibility (Gatignon and Xuereb, 1997; McKee et al., 1989), suggest that "a distinct strategic orientation serves as a clear organizational focus, which enables alignment with an appropriate innovation strategy" (Cheng and Huizingh, 2014: 1248). TRM is a framework for strategic decision-making, helping to "develop mid- to long-term technological strategies that can secure future technological alternatives for creating new technological innovations" (Lee et al., 2011: 486). TRM theories "provide a direction for future alignment of activities and planning" (Martin and Daim, 2012: 96),

while adapting to changing technological landscapes (Komninos et al., 2019). Therefore, this approach to innovation strategy formulation can also help examine how to manage technology life cycle stages, a major issue in SCD projects (Cetindamar et al., 2020). Additionally, TRM can help link "technical aspects such as hardware, software, data transmission and processing, to higher socio-technical levels such as users and application scenarios, and societal and community demands" (Mao et al., 2020: 9146).

Available data show that only a few urban areas like the City of Toronto (2022), and some Greek municipalities (Siokas and Tsakanikas, 2022) are employing TRM for their local digital innovation strategies. Moreover, there is a scarcity of studies examining TRM in the SCD context, with Lee et al. (2013) being a notable exception. Their study of a Korean SCD project shows that TRM supports strategic planning in complex digital innovation projects. Additionally, the authors outline an eight-phase process for practitioners to follow when developing strategies for their SCD projects following the TRM approach: planning, demand identification, service identification, device identification, technology identification, roadmap drafting, roadmap adjustment, and follow-up. However, in this case study, attention is mainly posed on practical implications rather than creating the basis for theoretical generalizations. Moreover, the contribution of this research addresses single-project-implementation questions rather than setting the stage for a line of inquiry that investigates strategy-related challenges by adopting a citywide perspective (Mao et al., 2020).

Additionally, examining strategy challenges through the lens of open strategy could also be beneficial (see Hautz et al., 2017). Flexibility is a key challenge for municipal governments in achieving citywide coordination (Brozovic, 2018), a task difficult to perform with traditional strategy processes (Hidalgo and Albors, 2008). Effective local digital innovation strategies for coordinating SCD projects should be adaptable over time. Traditional planning cycles often overlook the potential of bottom-up initiatives (Zygiaris, 2013), an essential component of SCD (Kumar et al., 2020). Open strategy, grounded in open innovation principles (see Chesbrough, 2003), can accommodate organic growth from various societal actors (Bush et al., 2017). This approach enables the integration of new trends and signals while maintaining strategic stability (Chesbrough and Appleyard, 2007).

Monitoring Challenge

Research into SCD project assessments remains limited (Gerogiannis and Manika, 2022). Current tools focus more on ranking cities based on "smart" characteristics rather than evaluating the quality and innovation of their smart city projects. Indexes like the Smart Cities Index and Smart City Observatory[2] exemplify this issue. Giffinger and Gudrun (2010) have noted a trend where the pursuit of high rankings overshadows genuine development. Sharifi (2019) criticizes the prevalent use of static Key Performance Indicators (KPIs) in SCD assessments for their lack of ongoing project monitoring. Kattel et al. (2018) have pointed out the absence of clear guidelines on measuring SCD projects and gathering relevant data. Moreover, De Sanctis et al. (2022) have exposed a significant gap in integrating different data sources in these assessments. Consequently, professionals in the SCD field struggle with a lack of monitoring and assessment tools

that can merge various data sources and adapt to specific local conditions (Gerogiannis and Manika, 2022; Monzon, 2015).

From an innovation management perspective, this gap is worrisome. It is widely acknowledged in innovation studies that monitoring processes are vital project activities and imply assessing social-technical transitions in the making (Farla et al., 2012). Effective monitoring is needed to enhance decision-making (De Oliveira et al., 2015) and project planning (Karo and Kattel, 2018).

Theory-building in this underexplored area of SCD research could benefit from advances in innovation indicators, both product- and process-oriented (Makkonen and van der Have, 2013). These indicators span from *ex ante*, assessing early stages of innovation, to *ex post*, evaluating post-market implementation. At the product level, *ex ante* indicators might include the number of patent applications or the novelty of SCD project solutions, while *ex post* indicators could focus on the number of new solutions introduced or their success rate. At the process level, *ex ante* indicators might involve time allocated for idea generation or management, while *ex post* indicators could measure the extent of process improvements or the rate of idea implementation (Dziallas and Blind, 2019). These examples illustrate how innovation theory can guide the selection of indicators to monitor the various phases of SCD project implementation and assess both tangible and intangible outcomes.

The integration of developmental evaluation into SCD projects addresses a significant gap in current literature. Traditional methods often fail to capture knowledge generated during projects, leading to issues like reduced innovation capacity and stakeholder exclusion (Brorström et al., 2018; Fernandez-Anez et al., 2020; Sharifi, 2019). Developmental evaluation is a method for supporting adaptation in complex environments, emphasizing participatory monitoring involving diverse stakeholders (Preskill and Beer, 2012). Various stakeholders collaborate in designing the monitoring process and simultaneously take on the key roles necessary to sustain its implementation—evaluator, learning facilitator, project manager, and innovator (Lam and Shulha, 2015)—making it particularly suitable for the dynamic nature of SCD projects and the cross-sector innovation ecosystems supporting their development.

Gothenburg, Sweden, is an example of a city where municipal staff recognized the need for developmental evaluation in SCD projects. In response to this need, they sought a tool that could measure normative and relatively easily quantifiable variables related to technical or financial aspects while also addressing the more challenging environmental and social dimensions, an endeavor perceived by staff as more difficult and complex to measure and communicate (Brorström et al., 2018). Similarly, Lam and Shulha (2015) demonstrated the effectiveness of developmental evaluation in a Canadian university's teacher education program, noting its capability to facilitate social innovation and lasting organizational change. They observed that this approach to monitoring provided timely data, aiding decision-makers in responding to evolving needs, and making necessary adjustments.

Patton (2016) describes developmental evaluation as method-agnostic; it grants flexibility when selecting the means for gathering data and can be complemented with monitoring practices that fit with the specific requirements of each project stage (Lam and Shulha, 2015). In SCD projects, this flexibility is particularly valuable as integrating forward-looking practices like technology assessment and scenario-building is

recommended (Truffer et al., 2017). While a combination of such approaches has been largely examined in the field of innovation, it is only scarcely considered in SCD research. These practices are understood "as a participatory form of future-oriented policy support" (Weber et al., 2019: 241), essential for anticipatory agenda setting and decision-making that can help stakeholders in SCD projects to formulate expectations about future developments and outcomes. This is a vital component given the non-linear and volatile nature of technology lifecycles.

Intermediation Challenge

The initiation of SCD projects is a collaborative endeavor, involving a range of actors beyond just municipal governments. This creates a dynamic yet intricate network of collaborations and outcomes. Research in SCD highlights the pivotal role of intermediary organizations in coordinating these efforts and mitigating siloed thinking within and across entities. These organizations, often referred to as smart city units (Mora et al., 2023) are instrumental in fostering local innovation networks and supporting SCD (Ferraris et al., 2018). Karimikia et al. (2022) argue that these units fulfil essential technical, cultural, political, and social roles. However, our understanding of smart city units remains limited (Bakici et al., 2013), with questions remaining about their power, organizational structure, integration into local governance, and resource implications (Ehnert et al., 2022; Kattel et al., 2018). Moreover, there is a lack of comprehensive empirical studies on the methods and processes that these organizations use to cultivate innovation networks. The transition from top-down to bottom-up governance models through smart city units warrants further investigation (Karimikia et al., 2022). Notably, there is an absence of a detailed taxonomy of smart city units, which are generally categorized as either internal departments within municipal governments or external organizations acting on their behalf (Mora et al., 2019). A more nuanced classification is needed.

Literature on innovation intermediaries could bridge the existing knowledge gaps in our understanding of smart city units. This stream of literature provides insights on how these units develop and coordinate the complex innovation ecosystems for SCD, catalyze and spread SCD project solutions (Rossi et al., 2022), and influence the design and implementation of SCD policies and strategies (Kivimaa and Martiskainen, 2018). Innovation management studies indicate that these intermediaries can be public or private organizations, networks, or even individuals (Ehnert et al., 2022; Sovacool et al., 2020) and operating across various sectors, geographic regions, and administrative levels (Kanda et al., 2020). Their multi-functional role in creating and sustaining innovation ecosystems (see below) is critical in complex settings like urban environments. Research on systemic intermediaries, which operate at a system or network level as opposed to conventional bilateral intermediaries, is particularly relevant (van Lente et al., 2003). Building on existing evidence, we can conclude that smart city units are required to facilitate bilateral interactions in SCD projects while assuming a city-wide coordinating role. Therefore, we consider theories on systemic intermediaries particularly suitable for theory-building in SCD debates.

SCD is often supported by intermediary organizations established or led by local governments (Ehnert et al., 2022). From a social-technical perspective, these organizations

function as incumbent intermediaries. Scholars such as Mukhtar-Landgren et al. (2019) or Sovacool et al. (2020) describe local governments as regime intermediaries who advance sustainability transitions and promote innovative governance approaches in urban spaces. As incumbent intermediaries, municipalities are well-positioned to leverage their existing authority and networks to support transformative projects while simultaneously safeguarding the stability of the urban system (Rossi et al., 2022). This dual role of bridging the gap between city administrations and innovative communities is a unique quality of incumbent intermediaries. They leverage their legitimate position and role in prioritizing city agendas (Mukhtar-Landgren et al., 2019). Innovation literature thus offers valuable insights into how municipalities can create effective intermediation spaces to manage complex collaborative environments with diverse smart city actors. But SCD research has yet to explore this theoretical lens.

Reflecting on different types of innovation intermediaries, innovation scholars have also developed taxonomies. Kivimaa et al. (2019) complemented systemic and incumbent intermediaries with niche, process, and user intermediaries. Howells (2006) proposed a comprehensive typology differentiating between organizational and process intermediaries, such as consultants, brokers, and boundary organizations. These include living labs, which are increasingly recognized as crucial for intermediation in SCD projects (Bulkeley et al., 2016; Steen and Van Bueren, 2017). They are conceived as collaborative environments "for fostering ideas and converting them into solutions" (Alam and Porras, 2018: 5). Effective in mediating between bottom-up and top-down dynamics, living labs facilitate experimentation and co-creation (Kronsell and Mukhtar-Landgren, 2018). They enable citizen engagement through "power banking" (Nguyen et al., 2022: 9): a process through which citizens are granted powers by the living lab coordinators, allowing them to obtain a certain level of formal authority and participate in formal governance arrangements. However, Nguyen et al. (2022) caution that living labs might inadvertently perpetuate power imbalances or transparency issues, affecting their impact (Mukhtar-Landgren et al., 2019).

Current literature on SCD has yet to fully delineate the key functions of smart city units, an area where innovation theory can provide valuable insights. For instance, Sovacool et al. (2020) categorize the functions of innovation intermediaries into six groups: knowledge and learning, networking, brokering, innovation and diffusion, visioning, and institutional roles. Building on this parallel between SCD studies and innovation literature, some of the other functions that smart city units fulfil include cross-project coordination (Martiskainen and Kivimaa, 2018), shaping of collaboration mechanisms (Smith et al., 2016), developing collective visions (Geels and Deuten, 2006), lobbying for new policies, technical standards, and regulations (Rohracher, 2009), and promoting institutional changes (van Mierlo and Beers, 2020).

Based on the above-presented concepts, we contend that observing smart city units through the lens of innovation intermediaries opens new theoretical avenues in smart city research. For instance, framing smart city units as innovation intermediaries enhances our understanding of their potential roles and positions in facilitating collaboration and resource allocation within a city's innovation ecosystem. Similarly, insights from the study of innovation intermediaries can guide the alignment of smart city project goals with wider urban strategies.

However, a critical question arises: do smaller urban areas, such as towns and villages, require these intermediary organizations, and can they sustain them? While larger cities often have dedicated smart city units, smaller areas face unique resource challenges. One potential solution is to rely on "charismatic leaders" (Michaelis et al., 2009: 513). This approach invites further investigation into the role of transformational and charismatic leadership within SCD (Aarons and Sommerfeld, 2012; Paulsen et al., 2009), potentially offering new insights on the scalability and adaptability of smart city intermediation strategies across different urban contexts.

Multilevel Governance Challenge

Multilevel governance involves a system where government authority is shared across various public administration levels and with different actors, both public and private (Varró and Bunders, 2019). This concept is particularly relevant in SCD research, which calls for new empirical studies and advanced theories (Homsy and Warner, 2015). For instance, Ciasullo et al. (2020) observed that in Trento, Italy, multilevel governance was critical to sustain cross-sector cooperation and knowledge sharing in SCD projects. Lange and Knieling (2020) discuss the European Union's impact on local SCD projects, particularly through its Horizon 2020 funding. They noted how this funding shaped the approach of Hamburg, Germany, to SCD projects in terms of conceptualization, participant involvement, and strategic implementation.

But multilevel governance can also create challenges, and current research mainly focuses on governance at a single level, rather than exploring inter-level dynamics (Varró and Bunders, 2019). National policies might overlook local needs (Ehnert et al., 2018), and national SCD strategies may conflict with local goals (Reardon et al., 2022). Furthermore, sustainability issues in SCD projects often require cooperation beyond a single municipality's scope, revealing the need for better horizontal and vertical coordination (Meijer et al., 2016; Termeer et al., 2010).

How can innovation theory help improve our understanding of multi-level governance in the SCD field? Boundary management theory, for instance, can help examine how institutional settings positioned at different administrative levels connect (or disconnect). In this theoretical framework, supralocal and local actors can be envisioned as components of boundary zones: "transitional areas" (Garzella et al., 2021: 31) in which different regulatory frameworks on SCD are required to coexist and where exchange of organizational resources take place. Boundary zones create a continuum (Normann and Ramirez, 1993) in which interactions between multi-scalar and cross-jurisdictional regulatory frameworks can be observed (Capurro et al., 2021) to identify friction or harmonized coordination (He and Berry, 2022).

The process of integrating boundaries is further captured by literature on scaling innovation. Scaling describes "the adaptation, uptake, and use of innovations … across broader communities of actors and/or geographies" (Schut et al., 2020: 1). It includes up-scaling (introducing innovations to higher levels), out-scaling (spreading innovations widely), and down-scaling (applying broader innovations locally) (de Roo et al., 2019; Hermans et al., 2016; Schut et al., 2020). These concepts can help address gaps in SCD governance literature, explaining how local conditions influence broader policies and how local and supra-local innovations interact.

Conclusion

This commentary critiques the limited theoretical foundation of SCD governance and illustrates how insights from innovation management studies can help bridge existing knowledge gaps, calling for more cross-disciplinary research in SCD domain. Our observation of SCD governance challenges through the lens of innovation management reveals untapped potential for theory development in the SCD field. Essentially, we show how innovation theory can serve as a springboard for novel SCD research. Our aim is to offer some stimuli that can catalyze cross-disciplinary research efforts, exploring the underutilized synergy between SCD studies and innovation management theory.

Our analysis is also instrumental in opening new avenues for research. First, we introduce sensemaking theory, which provides a valuable perspective against the prevalent techno-centric view of SCD transitions. A more nuanced definition of SCD as social-technical processes at various scales can emerge from this approach. Boundary objects play a key role here, offering a common foundation for understanding the SCD concept while allowing adaptation to local contexts.

Second, the principles of strategic orientation and flexibility from innovation studies offer a framework for examining the challenge of strategizing citywide coordination in SCD projects. This addresses the well-acknowledged need for orchestration in SCD projects, a challenge yet to be fully resolved in SCD research. Strategic orientation and flexibility can act as guiding tools for SCD project implementation, accommodating both planned and spontaneous, bottom-up efforts. Furthermore, we propose using technology roadmapping and open strategy as methods for examining the systematic strategizing of SCD projects.

Third, we link SCD research to discussions on innovation indicators and developmental evaluation practices. These theoretical stimuli can help generate monitoring and assessment tools that contrast with the static, one-size-fits-all performance metrics commonly used in SCD assessments. Innovation indicator theories emphasize the need for ongoing monitoring, while developmental evaluation offers a practical method for applying and operationalizing these indicators.

Fourth, we highlight the potential of literature on innovation intermediaries to help address a gap caused by an incomplete understanding of smart city units and a lack of clarity regarding their organizational design and routines. Studies on innovation intermediaries may help understand how complex innovation ecosystems behind SCD should be managed, how SCD project solutions can be catalyzed and diffused, and how SCD policies and strategies should be designed and implemented. In this theoretical framework, we believe that systemic intermediaries should take a central stage; their actions might be especially important in the context of SCD. Moreover, smart city units in which municipalities participate or lead may assume a transversal role as incumbent intermediaries.

Fifth, we reflect on how the innovation concepts of boundary management and scaling can inform the multifaceted nature of SCD processes across administrative levels. Many crucial aspects of local SCD projects are influenced by higher-level policies and regulations, often without adequate consideration of local needs. Boundary management theory offers insights into the interplay between different institutional levels, while scaling studies provide frameworks for adapting innovations and their conditions across various scales. This constitutes a new theoretical ground for SCD research.

Based on our argumentation, we conclude by stressing that innovation management studies offer promising avenues for advancing SCD theory. This commentary builds upon preliminary research that has investigated this nexus (see Costales, 2022; Karimikia et al., 2022; Lee, 2020; Leitheiser and Follmann, 2020; Nilssen, 2019; Paskaleva, 2011) and aims to accelerate theory development in SCD research through cross-fertilization with more theoretically developed fields. We anticipate that this will lead to a richer, more nuanced array of theoretical frameworks better suited to the complexities of managing SCD projects. We expect these theoretical frameworks to help bridge the gap between SCD theory and practice, helping practitioners in the SCD domain to obtain the knowledge that they need to sustain evidence-informed decisions and improve their SCD governance approaches.

Our approach to SCD governance through the lens of innovation management studies provides advantages to both streams of literature. However, our examination of innovation management is constrained by the limited scope of our commentary, whose primary focus is on advancing theory in SCD research. Through this commentary, we ultimately seek to foster a stronger, more consistent multidisciplinary connection in the study and practice of SCD governance. It is important to note that the innovation concepts discussed here are illustrative examples of how SCD and innovation theories can intersect to address gaps in SCD governance research. Likewise, the governance challenges highlighted are representative rather than exhaustive. While this commentary presents a promising direction for theoretical advancement, further exploration of these connections is essential.

We invite the scholarly community to expand upon the theories introduced in this commentary by conducting empirical research that explores their applicability in addressing SCD governance challenges. Existing studies provide promising evidence, but further efforts are needed to extend theoretical generalizations and practical applications. For example, while we introduce innovation management concepts with potential to inform SCD governance theory, additional research is needed to clarify how these can be effectively implemented in practice. Furthermore, a more diverse evidence base is necessary, as the cases referenced in this commentary are primarily from European and North American contexts—a common pattern in the literature on smart city governance and innovation management (Mora et al., 2017).

By embracing diverse theoretical perspectives from innovation management studies, and encouraging cross-disciplinary research, we can deepen our understanding of SCD governance. A collaborative approach, drawing on insights from mature research fields like innovation management, is essential for accelerating knowledge accumulation in the SCD domain.

Notes

1. While we acknowledge that the concept of SCD requires careful and context-dependent interpretations (see *Conceptualization Challenge*), in the scope of this commentary, we refer to SCD as an approach to urban innovation that implies introducing digital technologies and digital services in urban environments to improve their socioeconomic and ecological conditions and enhance the quality of life of their citizens.
2. See https://smartcitiesindex.org/smartcitiesindexreport2022 and https://www.imd.org/smart-city-observatory

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Notes on Contributors

Dominik Beckers is a doctoral candidate at Tallinn University of Technology, where he is collaborating with the FinEst Center for Smart Cities and the Academy of Architecture and Urban Studies.

Luca Mora is a professor of urban innovation at the Business School of Edinburgh Napier University and at Tallinn University of Technology.

ORCID

Luca Mora http://orcid.org/0000-0003-4680-6985

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There Is No Rose Without a Thorn: Examining the Contribution of Collaborative Platforms to Sustaining Collaborative Governance

Dominik Beckers[1] | Luca Mora[1,2] | Federico Platania[3] | Paolo Gerli[2]

[1]Tallinn University of Technology, Academy of Architecture and Urban Studies & FinEst Centre for Smart Cities, Estonia, UK | [2]Edinburgh Napier University, The Business School, Scotland, UK | [3]Institut Supérieur de Gestion, Paris, France

Correspondence: Luca Mora (L.Mora@napier.ac.uk)

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ABSTRACT

This study investigates the extent to which collaborative platforms contribute to strengthening the collaborative governance capacity of municipal governments, focusing on smart city development as an empirical context. Drawing on survey data from 289 municipal government officials and using a multinomial logit model, we test eight hypotheses linking collaborative platforms to key dimensions of collaborative governance: knowledge sharing, innovation culture, competences, strategic orientation, monitoring, vertical and internal coordination, and decision-making power. Our findings challenge the prevailing assumption that such platforms are uniformly beneficial. While their presence might support some collaborative governance dimensions, their contribution is less certain in others. Moreover, in some cases, our data shows that municipalities managing collaborative governance initiatives by means of a collaborative platform might perform just as well or even worse than those without one. These results suggest that expectations about collaborative platforms should be more carefully calibrated. By critically examining the contribution of collaborative platforms across key dimensions of collaborative governance, this study advances theoretical understanding and offers actionable insights for municipal platform managers and policymakers.

1 | Introduction

Addressing sustainability challenges increasingly requires public organizations to adopt collaborative governance (see Florini and Pauli 2018): a mode of policy and service delivery that moves beyond government- or market-centric approaches by involving public agencies, nonprofit organizations, and private businesses in joint decision-making and shared accountability, aimed at creating public value that none could achieve alone (Voets et al. 2021). Central to this concept is the recognition that governments cannot address the increasing complexity of societal challenges in isolation (Klijn et al. 2025). Therefore, collaborative governance emphasizes the importance of engaging both governmental and non-governmental actors in collective decision-making processes that promote cooperation across organizations, levels of government, and sectors (Emerson et al. 2012; Ran and Qi 2017).

Collaborative governance arrangements enable public institutions to work alongside diverse stakeholders to co-create and jointly implement initiatives—such as policies, strategies, programs, and projects—aimed at improving community outcomes and enhancing public service responsiveness (Ansell and Gash 2008). As Keast (2022, 491) notes, collaborative governance "moves beyond task integration to the synthesis of people and their resources for broader good." These arrangements are expected to enhance the capacity of the public sector to address complex policy issues and generate public value (Scott and Thomas 2017). By increasing legitimacy, pooling resources, and bridging institutional divides (Scott et al. 2019), collaborative

governance should help deliver more sustainable and more broadly supported policy solutions (Cinar et al. 2022).

However, collaborative governance arrangements do not always yield their intended outcomes (Angulo Amaya et al. 2020; Bertelli et al. 2020). Common barriers include conflicting interests among partners (H. Lee 2022), weak incentives for participation and joint decision-making (Newig et al. 2018), and limited trust or coordination (Florini and Pauli 2018). In response, public administration scholars increasingly advocate for *collaborative platforms* (Bizzo and Michener 2024; Hafer et al. 2024; Nambisan 2009): "an organization or program with dedicated competencies, institutions, and resources for facilitating the creation, adaptation, and success of multiple or ongoing collaborative projects or networks" (Ansell and Gash 2018, 20).

Typically managed by local public bodies, collaborative platforms engage in strategic intermediation to support the initiation and sustained management of collaborative governance efforts (H. Lee 2022). These platforms are expected to provide stable structures and regulatory frameworks for coordinating multiple collaborative initiatives and partnerships (Zhou and Dai 2022). They "specialize in facilitating, enabling and, to some degree, regulating many-to-many collaborative relationships" (von Heimburg et al. 2023, 27), integrating local knowledge and interests to scale collaborative efforts and enhance public value creation (Ansell and Torfing 2015).

Though often described "as a generic organizational logic" (Ansell and Gash 2018, 17), collaborative platforms are highly adaptable. They vary based on the objectives of collaborative governance arrangements, partnership configurations, collective and individual goals, institutional context, and geographical scope (Kilelu et al. 2013). Moreover, they can operate offline or online (Recalde et al. 2020) with different rules, sizes, and representation structures (Bell and Scott 2020).

Only recently public administration scholars have begun applying platform concepts, which originate in fields like engineering and technology, to governance and public management. As of today, research in this knowledge domain explores the role of collaborative platforms in supporting meta-governance (Farstad et al. 2022), orchestration (Ansell and Miura 2020), and the scaling of collaborative initiatives (Ansell and Torfing 2015). However, the effectiveness of platform-supported collaboration and the role of local authorities as platform owners remain underexplored in governance and public administration research (Ansell and Gash 2018). As the field remains theoretically and empirically nascent (Haveri and Anttiroiko 2023), existing claims about the benefits of these platforms in facilitating collaborative governance are often based on limited or inconsistent evidence, making it difficult to form realistic expectations (see Ansell and Miura 2020).

While initial findings offer valuable insights, they often derive from single case studies, limiting generalizability. Examples include *Newcastle City Futures* (United Kingdom) and the *Clean Cities* program (United States), which illustrate how platforms can facilitate collaborative governance in urban transformation and energy transition initiatives (H. Lee 2022; Vallance et al. 2020). However, the narrow scope of these cases constrains broader theory building.

Moreover, emerging critical perspectives further complicate the narrative. These views are underrepresented in mainstream discussions, but they cast doubts on the general effectiveness of collaborative platforms. For instance, Mu and Cui (2024) show how a mandated platform in China failed to sustain collaborative governance due to its rigid, top-down design. Similarly, Temmerman et al. (2021) describe a collaborative platform initiative in Brussels that stalled at implementation due to weak institutional commitment and inter-agency competition.

As H. Lee and Liu (2024) observe, current research trends hinder the field's ability to assess the broader potential and constraints of collaborative platforms, underscoring the need for more systemic and comparative inquiry. In response to this gap and an underdeveloped evidence base, this article addresses the following research question: *To what extent do collaborative platforms enhance the capacity of municipal governments to engage in collaborative governance?* We conceptualize collaborative governance capacity as a set of key dimensions identified in the literature as critical to the ability of municipal governments to initiate, coordinate, and sustain collaboration across sectoral and administrative boundaries. These collaborative governance dimensions include knowledge sharing (see del Busto et al. 2019; Garrido et al. 2025), innovation culture (see Demircioglu and Audretsch 2017; Torugsa and Arundel 2017), competences (see Gasco-Hernandez et al. 2022; Getha-Taylor and Morse 2013), strategic orientation (see Leipämaa-Leskinen et al. 2022; Sørensen and Torfing 2011), monitoring (see Kretschmer et al. 2022; Zhou and Dai 2022), vertical (see Jessop 2016; Piattoni 2009) and internal coordination (see Mora, Gerli, Batty, et al. 2025; Wheatley 2011), and decision-making power (see Klievink et al. 2016; Purdy 2012). The next section of the article explores each of these dimensions in detail.

To empirically investigate our reseacrh question, we focus on smart city development: an area of urban innovation characterized by complex collaborative governance demands coordinated by municipal governments (Vallance et al. 2020; Viale Pereira et al. 2017). Smart city development entails the collective engagement of societal actors in leveraging digital technologies to address urban sustainability challenges, enhance public service delivery, and improve city management (Mora, Gerli, Beckers, et al. 2025). These collective efforts span multiple policy domains (Bjørner 2021; A. Meijer and Bolívar 2015) and unfold through a constellation of interdependent projects initiated and led by actors from the public, private, academic, and civic sectors (Beckers and Mora 2025; Kivimaa 2014). The involvement of this multiplicity of actors contributes to blurred roles and responsibilities, with collaborative efforts shaping the design and delivery of smart city innovations (Voorwinden and Ranchordas 2021).

Within this decentralized landscape, collaborative governance provides a framework for aligning and integrating autonomous but interdependent project networks (Vallance et al. 2020). Municipal governments are tasked with orchestrating these efforts (Guenduez et al. 2024) and are expected to act as

institutional stewards of collaborative governance (A. J. Meijer et al. 2019, 2). To fulfill this role, many municipalities have introduced collaborative platforms for smart city development (hereafter CPDs) (see Mora, Gerli, Beckers, et al. 2025; Wheatley 2011), organizational entities established and managed by local public administrations (Alam and Porras 2018; Escobar and Henderson 2019). Reflecting broader trends in the collaborative governance literature, smart city research has begun to emphasize the potential of these platforms to strengthen the capacity of municipal governments for cross-sector coordination in the smart city context (see Dbouk et al. 2014; Stephenson et al. 2012; Vallance et al. 2020).

CPDs are designed to enhance coordination across sectors (Gilchrist et al. 2019; Ojasalo and Tähtinen 2016) and to provide "structured oversight for the diverse portfolio of technology projects serving the city" (Mora and Deakin 2019, 201). Their functions include consolidating stakeholder relationships, supporting the creation of citywide regulatory frameworks, aligning resources, and connecting smart city initiatives across governance levels and sectors (Mora, Gerli, Beckers, et al. 2025).

CPDs assume diverse organizational forms; some are embedded within municipal governments—situated in existing departments, established as new agencies, or organized as cross-departmental teams. Others operate as autonomous public organizations with independent legal status, albeit under municipal ownership and oversight (He et al. 2020; Karimikia et al. 2022). For instance, in Bogotá, Colombia, the CPD operates within the mayor's office (Ochoa Guevara et al. 2019; Sánchez-Vanegas et al. 2020). In Ramallah, Palestine, smart city coordination is handled by purpose-built cross-departmental teams and taskforces acting as platforms to facilitate collaboration among municipal units and external stakeholders (Mora, Gerli, Beckers, et al. 2025). In Helsinki, Finland, CPD responsibilities are assumed by Forum Virium Helsinki: an independent, non-profit organization owned by the municipal government but positioned outside its bureaucratic apparatus (Shamsuzzoha et al. 2021; Soe et al. 2022).

By systematically assessing the contribution of CPDs to key dimensions of collaborative governance, this study provides a more nuanced and evidence-based perspective on their role. The findings indicate that while CPDs may strengthen certain governance dimensions, their influence across all dimensions is not consistent. Moreover, some municipalities without CPDs were found to perform comparably well, or even better than those with such platforms, raising critical questions about their necessity and added value. These findings challenge the prevailing assumption that collaborative platforms are inherently beneficial and suggest that their contributions should be evaluated with greater caution.

This analysis draws on a global survey of individuals with in-depth knowledge of their city government and its approach to sustaining smart city development, the majority of whom are public sector officials. Conducted between December 2021 and March 2022, the survey generated 289 responses. We analyzed this data using a multinomial logit (MNL) model to examine whether the presence of a CPD correlates with improvements in the abovementioned collaborative governance dimensions, as claimed in the literature. These dimensions are reflected in eight hypotheses, which guided our evaluation.

This article proceeds as follows. Section 2 establishes the theoretical foundations of the study by reviewing how existing scholarship conceptualizes the role of collaborative platforms in supporting collaborative governance. Moreover, it introduces the hypotheses developed by building on this literature. Section 3 outlines the research design, data collection process, and analytical approach. Section 4 reports the findings, and Section 5 concludes with implications for theory and practice, limitations, and directions for future research.

2 | Theoretical Framing and Hypothesis Setting

This section presents eight hypotheses that reflect key theoretical claims regarding the contribution of collaborative platforms to the collaborative governance capacity of municipal governments. Each hypothesis targets a specific governance dimension that existing scholarship has identified as central to collaborative governance practice. These dimensions were selected based on a review of the literature, which highlights where claims about the value of collaborative platforms are most developed, while also indicating that other potential contributions remain insufficiently examined (see Vallance et al. 2020; Viale Pereira et al. 2017).

The formulation of the hypotheses draws on a cross-disciplinary body of scholarly work. While grounded primarily in public administration and governance research, our analysis incorporates relevant insights from adjacent fields—for example, urban studies, science and technology studies, and information systems—that have significantly contributed to the conceptualization and examination of collaborative platforms but are not situated within public administration and governance theory.

2.1 | Knowledge Sharing

The collaborative governance capacity of public organizations hinges on their ability to mobilize, integrate, and share knowledge across diverse stakeholders, including actors from the public, private, academic, and civil society sectors (del Busto et al. 2019; Garrido et al. 2025; Sandulli et al. 2017). These knowledge flows are fundamental to enabling collective problem-solving and advancing joint initiatives, making them a core dimension of collaborative governance capacity (Galeazzo and Furlan 2019).

Collaborative platforms are theorized to support these processes by structuring and facilitating knowledge-sharing activities across institutional and sectoral boundaries. Zhou and Dai (2022) describe how these platforms mobilize specialized knowledge to address complex policy issues, while Ansell and Gash (2018, 25) describe them as infrastructures that bring together stakeholders with "synergistic knowledge." Similarly, H. Lee (2022, 807) highlights their potential to connect "distributed knowledge" resources that would otherwise remain fragmented.

By embedding municipal governments in local, national, and international networks, collaborative platforms may enable

access to relevant knowledge, such as peer insights, best practices, and policy innovations (Baccarne et al. 2014; Ojasalo and Tähtinen 2016). This engagement helps cultivate institutional proximity—such as shared understandings, vocabularies, policy formulation, and practices—that underpins more durable forms of knowledge sharing (Crivello 2014; Nadim et al. 2022).

These claims support our first hypothesis:

H1. *Collaborative platforms increase the likelihood of municipal governments engaging in knowledge-sharing activities with other societal actors.*

2.2 | Innovation Culture

Organizational culture—understood as the set of shared values, norms, and beliefs that shape behavior within institutions—has important implications for the ways public organizations engage in collaborative governance (Nica 2013; Weare et al. 2014). Specifically, an innovation-oriented culture is associated with a greater capacity for collaborative governance, enabling municipal governments to experiment with and remain open to new collaborative approaches while revising established practices and routines (Demircioglu and Audretsch 2017; Park et al. 2021).

Moussa et al. (2018) argue that environments supportive of innovation enhance the ability of public actors to tolerate risk and engage in idea-sharing, experimentation, and cross-sector collaboration—behaviors closely tied to collaborative governance capacity (Asenova et al. 2015; Barrett 2022). Such cultures promote learning from failure, reduce fear of reputational loss, and encourage iterative problem-solving processes in complex collaborative settings (Adzariat et al. 2023) However, public sector organizations frequently struggle to embed these values due to institutional rigidity and low tolerance for both risk and failure (Torugsa and Arundel 2017, 900).

Collaborative platforms are theorized to offer institutional mechanisms that can help shift these dynamics. By acting as boundary-spanning spaces within municipal administrations, they can enable controlled experimentation with new products and services and shield emergent practices from premature termination (Kong and Woods 2018; Velsberg et al. 2020). Research also suggests that platforms may foster innovation mindsets by facilitating idea-sharing, supporting novel collaborative arrangements, and offering protected environments for pilot projects and cross-sectoral experimentation (Kummitha 2019).

This rationale leads to our second hypothesis:

H2. *Collaborative platforms increase the likelihood of municipal governments developing a culture supportive of innovation.*

2.3 | Competences

Collaborative governance demands a range of capabilities that extend beyond traditional administrative competencies. Effective collaboration across sectors and organizations requires municipal governments to develop specific forms of leadership, managerial agility, and technical proficiency. Getha-Taylor (2008) identifies foundational competencies such as inter-organizational understanding, teamwork, and leadership as critical for managing institutional boundaries. Getha-Taylor and Morse (2013) expand on this view, emphasizing collaborative problem-solving and the ability to manage fluid, inter-organizational networks—competencies that are poorly supported by conventional bureaucratic models.

This need for a broader know-how reflects the limitations of hierarchical governance structures in addressing the complexity and dynamism of multi-actor environments (Merritt and Kelley 2018). Capacity-building efforts in this context are not solely about individual expertise but also depend on supportive institutional settings. Gasco-Hernandez et al. (2022), for instance, highlight how collaborative governance capacity emerges through the interplay of leadership and organizational processes that facilitate coordination. A similar perspective also emerges from the work of Ansell and Torfing (2015), who argue that institutional designs should support adaptive management and cross-boundary problem-solving.

Collaborative platforms are presented as institutional mechanisms that can help cultivate these competencies. Abbate et al. (2022) show how platforms foster dynamic managerial capabilities such as strategic scanning, environmental sensing, and organizational learning. These capabilities are necessary for managing interdependent projects and coordinating across stakeholder groups. Garrido et al. (2025) describe how platforms support technical know-how by facilitating data integration and evidence-informed coordination. In the smart city context, Belanche-Gracia et al. (2015), F. Li et al. (2016), and Taylor Buck and While (2017) suggest that platforms contribute to developing the sociotechnical and managerial competences needed to govern complex innovation ecosystems.

This brings us to the third hypothesis:

H3. *Collaborative platforms increase the likelihood of municipal governments developing the leadership, managerial, and technical competences required to manage collaborative governance initiatives.*

2.4 | Strategic Orientation

The ability of municipal governments to engage in and sustain collaborative governance also depends upon their strategic orientation: how they set priorities, articulate long-term goals, and structure coordination across collaborative efforts (Akter-ujjaman et al. 2022). Strategic orientations influence whether inter-organizational collaboration generates innovation or leads to fragmentation and inefficiency (Sørensen and Torfing 2011). Therefore, public managers are expected to design and implement strategies that provide direction to multi-actor networks while aligning stakeholders around shared priorities (Favoreu et al. 2016).

Collaborative platforms are expected to strengthen strategic orientation by anchoring collaborative governance in shared objectives and mutual commitments. Ansell and Gash (2018)

argue that these platforms can help municipal administrations move beyond ad hoc collaboration by structuring governance arrangements around coherent, purpose-driven goals. In addition, collaborative platforms are seen to promote strategic alignment both within municipal administrations and across external partnerships, enhancing consistency and coordination across collaborative initiatives (Leipämaa-Leskinen et al. 2022).

Supporting this view, studies have shown instances in which platforms have facilitated the development of strategic tools—such as plans, frameworks, or roadmaps—that formalize collaborative priorities, define common goals, clarify roles and responsibilities of the parties involved, and outline mechanisms for coordination (Ojo et al. 2015). These tools can help consolidate fragmented initiatives under a unified strategic umbrella, enhancing coordination within government and across stakeholder groups (Praharaj et al. 2018; Trivellato 2016). From this perspective, collaborative platforms may enable municipal governments to articulate and institutionalize strategic approaches that integrate multiple collaborative projects and align partners around shared goals.

This leads to the fourth hypothesis:

H4. *Collaborative platforms increase the likelihood of municipal governments having an institutionally endorsed strategy that integrates multiple collaborative initiatives and aligns stakeholders around shared objectives.*

2.5 | Monitoring

Monitoring is a critical component of collaborative governance, allowing public organizations to assess progress across initiatives, determine whether shared goals are being met, and apply corrective measures to improve processes and outcomes (Sørensen and Torfing 2016; Waardenburg et al. 2025; Wilkins et al. 2016). Effective monitoring helps ensure accountability and supports adaptive learning, both of which are essential in complex, multi-actor environments (van Acker and Bouckaert 2018). For example, Zhou and Dai (2022, 190) argue that monitoring systems can reinforce "stakeholders' commitment to collaboration efforts by reshaping their incentives and creating strong interdependencies among actors."

Collaborative platforms are viewed as instruments that can enhance the monitoring capacities of municipal governments. Kretschmer et al. (2022) argue that these platforms play a central role in tracking implementation and coordination of cross-sector activities, contributing to more integrated oversight. This coordinating function is seen as essential to maintaining a healthy collaborative ecosystem (Bianchi 2022).

In addition, collaborative platforms can help consolidate data from multiple sources and apply performance metrics to evaluate the effectiveness of collaborative initiatives (Sharifi 2019). Some studies also emphasize their role in designing customized monitoring frameworks that generate actionable insights for improving implementation and supporting strategic decision-making (Prasad et al. 2021). As Patrão et al. (2020) note, these insights can enable municipal governments to fine-tune collaborative strategies and manage partnerships more effectively.

Based on this reasoning, we propose the following hypothesis:

H5. *Collaborative platforms increase the likelihood of municipal governments monitoring the collective progress and outcomes of collaborative governance initiatives.*

2.6 | Vertical Coordination

In collaborative governance arrangements, relevant resources, policy responsibilities, and implementation strategies are frequently distributed across multiple tiers of government—local, regional, national, and sometimes international (Piattoni 2009). Coordinating these multi-level elements is necessary to respond to policy challenges that exceed the jurisdictional reach and capacity of individual governments (Jessop 2016).

Collaborative platforms are theorized to support more effective engagement between municipal governments and higher levels of governance. For example, del Busto et al. (2019) describe the role of platforms in establishing mechanisms that bridge institutional divides across governance levels. Ehnert et al. (2018) similarly emphasize their potential to structure political frameworks and networks that foster multi-level alignment.

In governance areas characterized by overlapping competences, collaborative platforms are expected to mitigate fragmentation by linking national strategies with local implementation (Barns et al. 2017; Z. Li and Liao 2018). They can facilitate this alignment through co-designing policy interventions and coordinating resources and data flows that span jurisdictional boundaries (del Busto et al. 2019). In other words, platforms serve as intermediaries capable of translating between local and higher-level priorities, enabling municipal governments to better position themselves within broader governance architectures (Kitchin et al. 2016).

These considerations inform the following hypothesis:

H6. *Collaborative platforms increase the likelihood of vertical coordination between municipal and higher levels of government.*

2.7 | Internal Coordination

Municipal governments often operate with fragmented internal structures, where departments, teams, and units function in isolation, limiting opportunities for resource sharing and coordinated action (Steihaug et al. 2017). Wheatley (2011) attributes this fragmentation to entrenched organizational norms and rigid structures that, reinforced by habitual routines, constrain collaboration. These conditions pose substantial challenges for collaborative governance, particularly when internal misalignment weakens the ability of municipalities to contribute meaningfully to cross-sector initiatives (Afandi et al. 2023; Lekkas and Souitaris 2023; Warner 2006).

Collaborative platforms are expected to address such coordination gaps by strengthening interdepartmental connections and enhancing internal coherence. Suggested mechanisms include structured communication across units, shared repositories for organizational knowledge, alignment of departmental goals, and tools that allow administrators to identify and mobilize relevant internal expertise (Mora, Gerli, Beckers, et al. 2025; Nadim et al. 2022).

These claims are supported by Di Giulio and Vecchi (2023). Their study examines the case of the City of Milan, Italy, where a collaborative platform was introduced to address internal information silos. The platform has enabled departments to access and cross-reference multiple internal databases, improving data accessibility and integration across municipal units. Used by over 300 staff members, its adoption was voluntary and motivated by the practical benefits perceived by users. Therefore, this case illustrates how user-centered design and demonstrable usefulness can promote internal coordination and cross-departmental collaboration without the need for top-down mandates.

These insights suggest that collaborative platforms can help municipal governments reconfigure internal workflows and improve coherence across administrative boundaries, while also better aligning resources with collaborative governance efforts (Recalde et al. 2020; Timeus et al. 2020).

Based on these arguments, we advance the following hypothesis:

H7. *Collaborative platforms increase the likelihood of achieving coordination across departments and agencies within the municipal government.*

2.8 | Decision-Making Power

Collaborative governance brings together actors with varying degrees of influence, sparking concerns about potential power imbalances, particularly the risk that resource-rich private actors may dominate decision-making processes and marginalize public interests (Purdy 2012; Reff Pedersen et al. 2011). Such asymmetries can undermine the legitimacy and effectiveness of collaborative arrangements, in particular when public authorities are unable to assert their priorities or maintain oversight.

Available research shows that collaborative platforms might help address these challenges by establishing institutional safeguards that promote balanced participation. Klievink et al. (2016) and Leach et al. (2013) argue that collaborative platforms can create structured environments that foster sustained engagement and interdependence among actors. These environments facilitate collaboration as a process of mutual contribution, in which stakeholders collectively mobilize resources and expertise while advancing shared objectives (Thabit and Mora 2023). Therefore, it is claimed that collaborative ensure that no single actor dominates the agenda; they contribute to more equitable governance conditions (Wachhaus 2017).

In addition to shaping participatory dynamics, research also highlight that collaborative platforms can serve as formalized coordination mechanisms that integrate public and external actors into coherent governance frameworks. They function as neutral intermediaries and help establish procedural rules and expectations for joint decision-making (Coletta et al. 2019; Kraus et al. 2015). These functions are operationalized through tools such as open data platforms, stakeholder workshops, and digital coordination interfaces, which are designed to increase transparency and maintain institutional authority over collaborative processes (Garrido et al. 2025; Nadim et al. 2022). By institutionalizing participation and reinforcing public oversight, collaborative platforms are seen as mechanisms through which municipal governments can engage with private stakeholders while retaining sufficient decision-making power (Cao et al. 2023; Ran and Qi 2017).

Our final hypothesis builds on these claims:

H8. *Collaborative platforms increase the likelihood of municipal governments retaining decision-making power when collaborating with private actors.*

3 | Methodology

This study employs an exploratory research design, drawing on data gathered through a global survey of local smart city development experts working with or for the municipal government. Administered via *Qualtrics* between December 2021 and March 2022, the survey was designed to test the hypotheses presented in Section 2 by examining the contribution of CPDs to the eight collaborative governance dimensions we selected. Each hypothesis was operationalized through targeted survey items that capture relevant practices within the smart city domain. Details on the survey items corresponding to each hypothesis are provided in Section 4, where the empirical results are reported and examined.

The survey was designed and validated through a multi-stage process to ensure construct validity and content reliability. Iterative refinement was guided by extensive piloting with subject-matter experts representing diverse demographic, geographic, and disciplinary backgrounds in the smart city domain. These tests enabled the calibration of item formulations to ensure conceptual clarity, contextual relevance, and interpretability across a range of administrative and cultural settings.

The finalized survey was disseminated using a purposive sampling strategy. We combined direct emails with invitations sent by national and international smart city networks, cluster organizations, and professional associations. These intermediary organizations distributed the survey to representatives of municipalities involved in smart city initiatives, thereby enhancing the thematic relevance of the sample. To ensure inclusivity and improve global reach, the survey was translated into nine languages: Mandarin Chinese, Danish, English, Estonian, French, German, Italian, Portuguese, and Spanish.

The final dataset comprises 289 valid responses from individuals knowledgeable about their city government and its smart city development approach, with the majority being public officials

working for the municipal government. The respondents represent 65 countries across all continents except Oceania. Of these respondents, 163 reported that their municipality has established a CPD, while 91 indicated the absence of this platform. Thirty-five respondents selected the "don't know" category regarding CPD presence; these cases were excluded from subsequent statistical analysis to preserve analytical precision and internal consistency.

To test the proposed hypotheses, we employed a multinominal logit (MNL) model: an appropriate choice for modeling nominal dependent variables with three or more unordered categories. This econometric technique allows for the estimation of the relative log-odds of different outcomes as a function of one or more independent variables. Specifically, we used MNL to examine how the presence of a CPD influences the probability of different outcomes related to collaborative governance practices in smart city development.

Survey responses were pre-processed and structured using categorical scaling. Response options were classified into nominal and ordinal levels (e.g., *High*, *Medium*, *Low*; *Agree*, *Neither agree nor disagree*, *Disagree*; *Yes*, *No*) that reflect varying levels of intensity or agreement. Organizing the data into these categories allowed us to treat the outcome variables within an ordinal framework, capturing the nuances of respondents' attitudes, frequencies, and intensities.

The key independent variables—representing the decisions of municipal governments regarding collaborative governance dimensions for smart city development—were similarly categorized to ensure consistency across the dataset and streamline analysis. Both dependent and independent variables were transformed into dummy variables through dummy coding. This process involved creating binary indicators for each category, where each dummy variable was represented as a binary indicator (1 if the observation belonged to that category, 0 otherwise). For each regression, one category was defined as the categorical base or reference category against which all other categories were compared. This selection was crucial to avoid multicollinearity, which can distort regression estimates. This conversion allowed us to include categorical variables in the regression model without losing interpretability, as the coefficients of the dummy variables represent the effect relative to the reference category.

Using the dummy-coded variables, we fitted the MNL model. This model estimates the probability of each outcome category as a function of the independent variables. The general mathematical formulation is as follows:

$$\log\left(\frac{P(Y=j)}{P(Y=\text{Reference Category})}\right)=\beta_{0j}+\beta_{1j}X_1+\beta_{2j}X_2+\ldots+\beta_{pj}X_p$$

where $P\ (Y = j)$ is the probability of the outcome being in category j, β_{ij} are the coefficients for each independent variable X_i for category j, and the reference category is the categorical base against which comparisons are made.

The model parameters were estimated using maximum likelihood estimation, where the estimated coefficients indicate the change in the log odds of the outcome being in a particular category (vs. the reference category) for a one-unit change in the independent variable. Positive coefficients suggest an increase in the likelihood of the outcome category relative to the reference category, while negative coefficients indicate a decrease.

Our methodological approach involved careful data structuring by categorizing responses to reflect varying intensities and agreements, ensuring the data captured the necessary detail for analysis. By converting categorical variables into dummy variables, we included them effectively in the regression model. Applying the MNL model using maximum likelihood estimation allowed us to estimate the relationships between independent variables and categorical outcomes. With the subsequent analysis of the model outputs, we were able to understand the significance and direction of effects, providing insights into factors influencing decisions regarding collaborative governance arrangements for smart city development.

4 | Results

H1. *Collaborative platforms increase the likelihood of municipal governments engaging in knowledge-sharing activities with other societal actors.*

To test H1, respondents were asked whether the municipal government they represent engages in inter-organizational knowledge-sharing activities relevant to smart city development. These activities include: (1) knowledge-sharing at the local level, with other actors in the city (e.g., other public organizations, universities, local businesses, citizens); (2) knowledge-sharing through national networks, platforms, or programs (e.g., national forums, national working groups, national collaboration schemes); (3) knowledge-sharing through international networks, platforms, or programs (e.g., EU projects, global city alliances). Based on the number of reported activities, respondents were categorized into four ordinal groups: *None* (no reported activity, used as the reference category for comparison), *Low* (engagement in one activity), *Medium* (two activities), and *High* (all three activities).

The regression results in Table 1 indicate that municipalities with a CPD (Parameter *Yes*) exhibit positive and statistically significant coefficients across the *Low*, *Medium*, and *High* categories relative to the *None* categorical base. The estimated coefficients are 1.6094 ($p = 0.011$) for the *Low* category, 2.3979 ($p < 0.001$) for *Medium*, and 3.6199 ($p < 0.001$) for *High*. These coefficients represent the log-odds of a municipality falling into each respective knowledge-sharing category compared to the categorical base, conditional on the presence of a CPD.

For a more intuitive interpretation, municipalities with a CPD are approximately five times more likely to fall into the *Low* category (exp^1.6094 ≈ 5.00), eleven times more likely to be in the *Medium* category (exp^2.3979 ≈ 11.00), and thirty-seven times more likely to belong to the *High* category

(exp^3.6199 ≈ 37) compared to those not engaged in any knowledge-sharing activities.

Consequently, the results provide support for H1, indicating a strong positive association between the presence of a collaborative platform and the likelihood of municipal-level engagement in knowledge-sharing initiatives. Municipalities with a CPD are more likely to report participation in one or more of these initiatives compared to those without a collaborative platform, and they tend to engage in a broader range of activities. These findings suggest that collaborative platforms may contribute to enhancing the knowledge-sharing capacity of municipal governments.

H2. *Collaborative platforms increase the likelihood of municipal governments developing a culture supportive of innovation.*

For H2, the survey assessed whether municipal administrations adopt organizational practices that support innovation-related behaviors in the context of smart city development, such as encouraging experimentation, openness to new ideas and complex collaborations, risk-taking, and learning from failure. Responses were categorized into three levels: *Agree*, *Neither agree nor disagree* (reference category), and *Disagree*.

The results, summarized in Table 2, reveal a strong positive association between the presence of collaborative platforms (Parameter *Yes*) and the likelihood of municipal governments being supportive of innovation-oriented practices. The estimated coefficient for municipalities with a CPD in the *Agree* category is 1.6818 ($p < 0.001$), indicating that they are approximately five times more likely to report these supportive practices than the municipalities in the neutral category (exp^1.6818 ≈ 5).

Conversely, the absence of a CPD is associated with a significantly lower likelihood of selecting the *Disagree* category. The corresponding negative coefficient (−0.9808, $p = 0.012$) suggests that municipalities with a CPD are about 0.38 times as likely to report an absence of supportive innovation practices relative to the neutral group (exp^−0.9808 ≈ 0.38).

But even in the absence of a CPD (Parameter *No*), municipalities show a positive association with the *Agree* category. The estimated coefficient of 1.1741 ($p < 0.001$) suggests that these municipalities are nearly three times more likely to report having innovation-supportive practices than those in the neutral group.

These findings suggest that while collaborative platforms substantially increase the likelihood that municipal administrations possess an innovation-oriented culture, by a factor of approximately five, such culture may also develop under alternative institutional arrangements, though with a comparatively lower likelihood, around three times higher than the neutral baseline.

H3. *Collaborative platforms increase the likelihood of municipal governments developing the leadership, managerial, and technical competences required to manage collaborative governance initiatives.*

H3 was examined by asking respondents to indicate the extent to which they agreed that their municipality possesses the leadership, managerial, and technical competencies required to coordinate smart city initiatives. As shown in Table 3, the presence of a CPD (*Yes* parameter) is strongly and positively associated with the *Agree* category relative to the categorical base (*Neither agree nor disagree*), with an estimated coefficient of 0.7450 ($p < 0.001$). This suggests that municipalities with a CPD are approximately twice as likely to report having the

TABLE 1 | Results for hypothesis 1.

	Low				Medium				High			
			5% distribution				5% distribution				5% distribution	
Parameter	**Estimate**	***p*-value**	**0.025**	**0.975**	**Estimate**	***p*-value**	**0.025**	**0.975**	**Estimate**	***p*-value**	**0.025**	**0.975**
No	−0.1112	0.739	−0.766	0.543	0.1466	0.640	−0.467	0.760	0.5521	0.055	−0.012	1.117
Yes	1.6094	0.011	0.370	2.849	2.3979	0.000	1.216	3.580	3.6199	0.000	2.473	4.767
R^2						0.09999						
Log likelihood						−311.98						
Categorical base	None (no participation in any knowledge sharing activities)											

TABLE 2 | Results for hypothesis 2.

	Disagree				Agree			
			5% distribution				5% distribution	
Parameter	**Estimate**	***p*-value**	**0.025**	**0.975**	**Estimate**	***p*-value**	**0.025**	**0.975**
No	0.0572	0.866	−0.606	0.720	1.1741	0.000	0.630	1.718
Yes	−0.9808	0.012	−1.747	−0.215	1.6818	0.000	1.246	2.177
R^2				0.03639				
Log likelihood				−185.61				
Categorical base	Neither agree nor disagree							

necessary competencies (exp^0.7450 ≈ 2) compared to those expressing neutrality.

In addition, the presence of a CPD is negatively associated with the likelihood of reporting a lack of such competencies. The estimated coefficient for the *Disagree* category is −1.0776 ($p < 0.001$), indicating that municipalities with a CPD are about 0.34 times as likely (exp^−1.0776 ≈ 0.34) to disagree, compared to the base category.

Interestingly, even municipalities without a CPD (*No* parameter) show a positive but smaller association with the *Agree* category (coefficient = 0.5664, $p = 0.038$), implying they are approximately 1.8 times more likely than neutral respondents to report having relevant competencies (exp^0.5664 ≈ 1.8). However, this effect size is smaller than the effect observed for municipalities with a CPD, indicating a relatively weaker association. Moreover, for the *Disagree* category, the absence of a CPD is not statistically significant (coefficient = 0.3895, $p = 0.168$), suggesting that the lack of a CPD does not influence the likelihood of disagreement compared to the categorical base.

These findings suggest that collaborative platforms may increase the likelihood that municipal governments develop leadership, managerial, and technical competences necessary to coordinate and sustain collaborative governance initiatives. Although such capabilities can also emerge in the absence of collaborative platforms, their presence is more strongly associated with higher perceived coordination capacity. Therefore, our results suggests that while a collaborative platform is not a prerequisite for the development in competences relevant to managing collaborative governance, it may play a supportive role in competence development.

H4. *Collaborative platforms increase the likelihood of municipal governments having an institutionally endorsed strategy that integrates multiple collaborative initiatives and aligns stakeholders around shared objectives.*

To assess H4, respondents were asked whether their municipality has a formally adopted strategy—such as strategic plans, roadmaps, strategic frameworks, vision statements, or equivalent policy documents—specifically designed to coordinate smart city initiatives in the city while aligning stakeholders around a shared vision and mutual objectives. Results (see Table 4) show a positive and statistically significant association between the presence of a CPD (*Yes* parameter) and having such a strategic orientation, relative to the *No* category. The estimated coefficient of 0.3597 ($p = 0.024$) indicates that municipalities with a CPD are approximately 1.5 times more likely to report having a strategy for smart city development (exp^0.3597 ≈ 1.5).

In contrast, the absence of a CPD (*No* parameter) is significantly and negatively associated with the likelihood of possessing a formally adopted strategy, with a coefficient of −1.1431 ($p < 0.001$). This suggests that municipalities without a CPD are substantially less likely to report having approved a strategy for guiding citywide smart city efforts.

Taken together, these results support H4; the presence of a collaborative platform is associated with a greater likelihood of municipal governments establishing a formalized strategy to coordinate and align smart city initiatives and stakeholders.

H5. *Collaborative platforms increase the likelihood of municipal governments monitoring the collective progress and outcomes of collaborative governance initiatives.*

To evaluate H5, respondents were asked to indicate whether their municipality has implemented a monitoring system to track the collective progress and outcomes of smart city projects developed in the city. Responses were coded as binary variables, distinguishing between municipalities with and without such systems.

The results (see Table 5) show no statistically significant association between the presence of a CPD (*Yes* parameter) and the likelihood of having a monitoring system (estimate of 0.0123 with $p = 0.938$), relative to the categorical base. However, the absence of a CPD (*No* parameter) is significantly and negatively associated with monitoring system presence. The estimated coefficient of −1.2669 ($p < 0.001$) suggests that municipalities

TABLE 4 | Results for hypothesis 4.

	Yes (strategic orientation)			
			5% distribution	
Parameter	**Estimate**	***p*-value**	**0.025**	**0.975**
No	−1.1431	0.000	−1.650	−0.183
Yes	0.3597	0.024	0.048	0.672
R^2	0.2248			
Log likelihood	−153.83			
Categorical base	No (strategic orientation)			

TABLE 3 | Results for hypothesis 3.

	Disagree				Agree			
			5% distribution				5% distribution	
Parameter	**Estimate**	***p*-value**	**0.025**	**0.975**	**Estimate**	***p*-value**	**0.025**	**0.975**
No	0.3895	0.168	−0.164	0.943	0.5664	0.038	0.031	1.102
Yes	−1.0776	0.000	−1.645	−0.510	0.7450	0.000	0.398	1.092
R^2	0.04557							
Log likelihood	−239.45							
Categorical base	Neither agree nor disagree							

without a CPD are approximately 72% less likely (exp^ −1.2669 ≈ 0.28) to have such systems in place.

Although these findings indicate that the absence of a CPD strongly correlates with a lack of monitoring systems, Hypothesis 5 is not supported. The presence of a collaborative platform does not increase the likelihood that municipalities adopt monitoring practices in collaborative governance initiatives, suggesting that other institutional or contextual factors may play a more decisive role than these platform-based entities.

H6. *Collaborative platforms increase the likelihood of vertical coordination between municipal and higher levels of government.*

H6 was tested by asking respondents whether they consider the coordination between their municipality and higher-level governments—for example, regional or national—effective in the smart city field. Responses were grouped into *Disagree*, *Neither agree nor disagree* (reference category), and *Agree* (see Table 6).

The results demonstrate a statistically significant negative relationship between the presence of a CPD (*Yes* parameter) and the *Disagree* category, with a coefficient of −0.4829 ($p = 0.041$). This indicates that municipalities with a CPD are approximately 38% less likely (exp^–0.4829 ≈ 0.62) to report misalignment between government levels compared to the neutral baseline.

Conversely, for the *Agree* category, the association is positive and statistically significant for municipalities with a CPD (coefficient = 0.5443, $p = 0.003$), implying that they are about 1.7 times more likely (exp^0.5443 ≈ 1.72) than neutral respondents to report vertical coordination.

TABLE 5 | Results for hypothesis 5.

	Yes (monitoring system)			
			5% distribution	
Parameter	**Estimate**	***p*-value**	**0.025**	**0.975**
No	−1.2669	0.000	−1.763	−0.771
Yes	0.0123	0.938	−0.295	0.319
R^2	0.2253			
Log likelihood	−147.56			
Categorical base	No (monitoring system)			

Municipalities without a CPD (*No* parameter) also show a significant positive association with *Agree* (coefficient = 0.5423, $p = 0.031$), suggesting a similar 1.7-fold increase in the likelihood of reporting vertical coordination.

These findings provide partial support for H6: the presence of a collaborative platform is associated with a higher likelihood of improved vertical coordination. However, the similar effect observed in municipalities without a CPD suggests that vertical coordination is influenced by other institutional or contextual factors, raising questions about whether collaborative platforms are a necessary catalyst for this dimension of collaborative governance.

H7. *Collaborative platforms increase the likelihood of achieving coordination across departments and agencies within the municipal government.*

To test H7, respondents were asked to assess the extent to which smart city collaboration within their municipal government is characterized by effective coordination across departments, units, and agencies—for example, through shared communication, joint decision-making, or integrated planning and policy formulation.

As presented in Table 7, the results indicate a statistically significant and positive relationship between the presence of a CPD (*Yes* parameter) and the *Agree* category. The coefficient for having a CPD is 1.6094 ($p < 0.001$), indicating that municipalities with a CPD are approximately five times more likely (exp^1.6094 ≈ 5) to report effective internal coordination compared to those who selected the categorical base (*Neither agree nor disagree*).

However, municipalities without a CPD (*No* parameter) also exhibit a significant positive association with the *Agree* category, with a coefficient of 0.6737 ($p = 0.005$). This implies that, in the absence of a CPD, municipalities are approximately twice as likely (exp^0.6737 ≈ 2) to agree that internal coordination is effective compared to the categorical base. Although CPDs are linked to a stronger likelihood of efficient internal collaboration, these findings indicate that coordination can still function effectively without such a platform.

Moreover, CPD presence and absence are significantly and negatively correlated with the *Disagree* category, reflecting a lower probability of reporting poor coordination. Municipalities

TABLE 6 | Results for hypothesis 6.

	Disagree				Agree			
			5% distribution				5% distribution	
Parameter	**Estimate**	***p*-value**	**0.025**	**0.975**	**Estimate**	***p*-value**	**0.025**	**0.975**
No	−0.2231	0.457	−0.811	0.365	0.5423	0.031	0.049	1.035
Yes	−0.4829	0.041	−0.946	−0.020	0.5443	0.003	0.185	0.904
R^2	0.07006							
Log likelihood	−233.85							
Categorical base	Neither agree nor disagree							

with a CPD exhibit a coefficient of −0.7340 ($p = 0.037$), corresponding to an approximately 52% lower likelihood of reporting poor internal coordination (exp^−0.7340 ≈ 0.48). Similarly, municipalities without a CPD have a coefficient of −0.8602 ($p = 0.017$), translating to a 58% lower probability of disagreeing with the initial statement (exp^−0.8602 ≈ 0.42).

Therefore, these findings generally support H7, confirming that the presence of a collaborative platform is associated with a higher likelihood of effective internal coordination. However, the results also suggest that effective coordination is not solely dependent on the presence of a collaborative platform. With both scenarios—presence and absence of a collaborative platform—municipalities report a low probability of weak coordination.

H8. *Collaborative platforms increase the likelihood of municipal governments retaining decision-making power when collaborating with private actors.*

For testing H8, respondents were asked to assess whether their municipal government maintains strong decision-making power in smart city initiatives involving private partners. Responses were categorized as *Disagree*, *Neither agree nor disagree* (reference category), and *Agree*.

As shown in Table 8, the results indicate a statistically significant and positive association between the presence of a CPD (*Yes* parameter) and the *Agree* category, with an estimated coefficient of 2.4323 ($p < 0.001$). This suggests that municipalities with a CPD are approximately 11 times more likely (exp^2.4323 ≈ 11) to report sufficient decision-making power in public-private collaborations compared to those expressing neutrality (*Neither agree nor disagree*).

However, municipalities without a CPD (*No* parameter) show an even stronger association with the *Agree* category. The *No* parameter is statistically significant with an even higher coefficient of 2.5390 ($p < 0.002$). Therefore, municipalities without a CPD are approximately 13 times more likely (exp^2.5390 ≈ 13) to have effective decision-making power compared to those who selected the categorical base (*Neither agree nor disagree*).

These findings do not unequivocally support H8. While CPDs are associated with a higher likelihood of decision-making power in public-private collaboration, the even greater likelihood observed in municipalities without a CPD suggests that other governance mechanisms or institutional arrangements may also be highly effective in preserving municipal power. This raises questions about the necessity of collaborative platforms in strengthening this dimension of collaborative governance.

5 | Discussion and Conclusion

Our findings provide mixed evidence, supporting only two of the eight hypotheses without ambiguity (see Table 9). First, the presence of a CPD is strongly associated with an increased likelihood that municipal governments engage in knowledge-sharing activities across local, national, and international arenas (H1). Second, CPDs are linked to a higher likelihood of municipalities having a formalized strategy that integrates smart city initiatives and aligns stakeholders around shared objectives (H4). These results highlight two specific collaborative governance dimensions—knowledge sharing and strategic orientation—where CPDs appear to make a positive and consistent contribution to collaborative governance capacity.

TABLE 7 | Results for hypothesis 7.

	Disagree				Agree			
			5% distribution				5% distribution	
Parameter	**Estimate**	***p*-value**	**0.025**	**0.975**	**Estimate**	***p*-value**	**0.025**	**0.975**
No	−0.8602	0.017	−1.565	−0.155	0.6737	0.005	0.201	1.146
Yes	−0.7340	0.037	−1.422	−0.046	1.6094	0.000	1.180	2.039
R^2				0.09046				
Log likelihood				−179.83				
Categorical base				Neither agree nor disagree				

TABLE 8 | Results for hypothesis 8.

	Disagree				Agree			
			5% distribution				5% distribution	
Parameter	**Estimate**	***p*-value**	**0.025**	**0.975**	**Estimate**	***p*-value**	**0.025**	**0.975**
No	0.4055	0.442	−0.628	1.438	2.5390	0.000	1.708	3.370
Yes	−1.8718	0.014	−3.361	−0.383	2.4323	0.000	1.865	2.999
R^2				0.04612				
Log likelihood				−106.79				
Categorical base				Neither agree nor disagree				

TABLE 9 | Summary of findings: Lessons from collaborative platforms for smart city development.

Hypotheses	Findings
H1 Collaborative platforms increase the likelihood of municipal governments engaging in knowledge-sharing activities with other societal actors.	• Municipalities with a CPD are significantly more likely to engage in knowledge-sharing activities. • They are also more likely to engage in a greater number of such activities.
H2 Collaborative platforms increase the likelihood of municipal governments developing a culture supportive of innovation.	• CPDs increase the likelihood of municipal governments fostering an innovation-supportive culture. • However, this culture may also develop in the absence of a CPD, suggesting their influence is not decisive for capacity building.
H3 Collaborative platforms increase the likelihood of municipal governments developing the leadership, managerial, and technical competences required to manage collaborative governance initiatives.	• CPDs are associated with an increased likelihood of municipalities having relevant competences for coordinating collaborative efforts in the smart city field. • Nonetheless, these competences may also emerge without a CPD, indicating that CPDs are not a necessary condition for capacity building.
H4 Collaborative platforms increase the likelihood of municipal governments having an institutionally endorsed strategy that integrates multiple collaborative initiatives and aligns stakeholders around shared objectives.	• CPDs significantly increase the likelihood that municipalities have a formal strategy for smart city development. • The absence of a CPD reduces this likelihood.
H5 Collaborative platforms increase the likelihood of municipal governments monitoring the collective progress and outcomes of collaborative governance initiatives.	• The presence of a CPD does not increase the likelihood of adopting a monitoring system. • However, the absence of a CPD is associated with a decreased likelihood of monitoring, suggesting that CPDs are not sufficient drivers of capacity for this collaborative governance dimension.
H6 Collaborative platforms increase the likelihood of vertical coordination between municipal and higher levels of government.	• CPDs are associated with a higher likelihood of vertical coordination. • However, municipalities without a CPD report similar or even stronger likelihoods, questioning the added value of CPDs for this dimension.
H7 Collaborative platforms increase the likelihood of achieving coordination across departments and agencies within the municipal government.	• CPDs increase the likelihood of effective internal coordination within the municipal government. • Yet, strong internal coordination is also observed in municipalities without a CPD, indicating that such platforms are not essential. • Both with and without CPDs, weak internal coordination is unlikely.
H8 Collaborative platforms increase the likelihood of municipal governments retaining decision-making power when collaborating with private actors.	• While CPDs are linked to a higher likelihood of municipalities retaining decision-making power when collaborating with private actors, municipalities without CPDs show an even stronger association. • This suggests that alternative mechanisms may be more effective than CPDs in ensuring public authority in smart city collaborations.

By contrast, H5 is not supported. The presence of a CPD does not increase the likelihood that municipalities adopt monitoring systems for tracking the progress and outcomes of smart city initiatives. This suggests that CPDs may have limited influence on developing monitoring capacity, which may instead be shaped by other institutional or contextual factors.

The remaining hypotheses (H2, H3, H6, H7, and H8) point to a more nuanced role of CPDs. While the presence of a CPD is positively and significantly associated with an increased likelihood of developing the targeted capacities—including fostering an innovation-supportive culture (H2), strengthening relevant competences for managing collaborative governance initiatives

(H3), improving vertical (H6) and internal (H7) coordination, and retaining decision-making power in public-private collaborations (H8)—municipalities without a CPD also show significant and sometimes stronger associations with these capacities.

These findings suggest that CPDs might support collaborative governance capacity but are not necessarily decisive. Their contribution appears contingent rather than universal. Most notably, in the cases of vertical coordination (H6) and decision-making power in public-private partnerships (H8), municipalities without CPDs exhibit likelihoods that are comparable to or greater than those with CPDs. This raises questions about the necessity of CPDs as a mechanism for strengthening collaborative governance.

Overall, our findings challenge assumptions that CPDs are uniformly beneficial. While CPDs might increase the likelihood of municipal governments developing certain collaborative governance capacities, their absence does not necessarily preclude such developments. These findings call for more tempered and context-sensitive expectations regarding the role of CPDs in supporting collaborative governance.

5.1 | Theoretical Contribution

This study advances the literature on collaborative platforms and collaborative governance by critically interrogating prevailing assumptions on the benefits of introducing collaborative platforms as a mechanism to increase the collaborative governance capacity of municipal governments. In contrast to the dominant theoretical narrative that often portrays collaborative platforms as uniformly supportive of collaboration (see Abbate et al. 2022; Bianchi 2022; del Busto et al. 2019; Klievink et al. 2016; Leipämaa-Leskinen et al. 2022), our findings reveal a more complex and contingent picture. Through the analysis of eight collaborative governance dimensions, this study provides a more granular understanding of where and how collaborative platforms may (or may not) contribute to strengthening collaborative governance capacity.

5.1.1 | Knowledge Sharing

"Realizing successful collaborative governance processes means organizing inclusion of [...] different components of knowledge" (van Buuren 2009, 208). Scholars have emphasized the role of knowledge intermediaries in addressing the challenges of knowledge sharing across diverse stakeholder groups. For instance, De Silva et al. (2018, 71) describe intermediaries as "knowledge repositories that introduce new combinations of knowledge", while Strambach and Surmeier (2018) highlight their function in managing knowledge contextualization, enabling the adaptation of information across organizational and sectoral boundaries.

Our findings suggest that collaborative platforms may function as such knowledge intermediaries by increasing the likelihood that municipal governments engage in knowledge-sharing activities across local, national, and international arenas. In this role, collaborative platforms appear to support two distinct but complementary functions: *dissemination*, referring to the unidirectional transfer of knowledge from the municipality to external stakeholders; and *exchange*, involving mutual and iterative knowledge flows between actors (Bäumle et al. 2022).

This capacity for knowledge dissemination and exchange may enable municipal governments to participate more actively in what De Silva et al. (2018, 72) term "ecosystem knowledge shaping": the strategic deployment of knowledge to influence the interests, practices, and routines of other actors. Through such processes, collaborative platforms might help develop shared understanding and mutual learning, reinforcing collaborative governance arrangements (Arnold et al. 2010). However, as further discussed in Section 5.1.3 in the context of H3 (Competences), the presence of a collaborative platform does not guarantee that shared knowledge is effectively absorbed or translated into increased institutional capacity, highlighting the potential limits of this intermediary function.

5.1.2 | Innovation Culture

In the collaborative governance literature, institutional design is frequently positioned as a foundational element for fostering cultures supportive of innovation. Ansell and Gash (2008) argue that the institutional design of collaborative frameworks influences the conditions necessary for innovation cultures to flourish. Emerson and Nabatchi (2015) similarly emphasize the importance of institutional structures in sustaining innovation cultures.

Collaborative platforms are often conceptualized as instruments of institutional design capable of embedding these enabling conditions within municipal governance arrangements (Kong and Woods 2018; von Heimburg et al. 2023; Zhou and Dai 2022). However, our findings call this assumption into question. While municipalities with collaborative platforms are more likely to report an innovation-oriented culture, the presence of such a platform is not a necessary condition. Municipalities without a collaborative platform also demonstrate comparable levels of innovation-supportive practices, suggesting that other institutional or contextual factors may be at play.

5.1.3 | Competences

Our findings suggest that collaborative platforms increase the likelihood that municipal governments develop the leadership, managerial, and technical competences needed to manage collaborative governance initiatives. However, these competences might also emerge without such platforms, indicating that they might not be a necessary condition for the development of competences.

This ambiguity is especially notable when considering our findings on knowledge sharing (H1), which indicate that collaborative platforms increase the likelihood that municipalities participate in knowledge-sharing activities. Collaborative governance literature often assumes a strong link between access to external knowledge and internal competence building. For example, Abbate et al. (2022), Baccarne et al. (2014) and

Ojasalo and Tähtinen (2016) suggest that participating in knowledge networks via collaborative platforms facilitate organizational learning and competence development by fostering institutional proximity and peer-based exchange.

However, our results do not provide clear evidence that the increased likelihood of knowledge sharing translates into the development of competences. This suggests a potential disconnect between the availability of external knowledge and its internal absorption within municipal structures. While collaborative platforms may help disseminate and exchange knowledge, they might not enhance municipalities' absorptive capacity: their ability to internalize and apply knowledge to improve collaborative governance performance (van Buuren 2009). This finding raises doubts about claims that position collaborative platforms as tools for overcoming barriers to organizational learning (see Garrido et al. 2025; Parker and Hine 2014). Rather, it suggests that collaborative platforms may not automatically overcome the absorptive capacity limitations often observed in public organizations (Ferraris et al. 2018), and that the transformation of shared knowledge into actionable competences is far from guaranteed.

5.1.4 | Strategic Orientation

Strategic orientation has been theorized to moderate the relationship between collaborative governance initiatives and the outcomes they produce (Nassani and Aldakhil 2023). Within collaborative governance literature, the role of strategic orientation is often framed as a coordination mechanism that enables the convergence of differing interests and competences required for the execution of collaborative initiatives (Akterujjaman et al. 2022; Cheng and Huizingh 2014), particularly in collaborative governance settings where the objectives of multi-sector partners may diverge considerably (Favoreu et al. 2016; Fedorowicz et al. 2009).

However, our findings suggest that this assumed alignment between strategy and implementation capacity may not always hold in the context of collaborative platforms. While H4 confirms that collaborative platforms increase the likelihood of municipalities adopting institutional strategies for collaborative governance initiatives, this does not appear to be consistently accompanied by a greater likelihood of developing the leadership, managerial, and technical competences required to sustain these arrangements (H3), which are relevant for strategy implementation (Getha-Taylor 2008; Getha-Taylor and Morse 2013). This discrepancy invites a reconsideration of the theorized connection between strategic orientation and capacity building (Bryson and George 2020) in the context of collaborative platforms. Our results suggest that while collaborative platforms may help structure strategic orientations, they might not foster the development of the organizational competences needed to implement those strategies.

Further concerns arise when considering the relationship between strategic orientation and decision-making power. While our results for H4 show that collaborative platforms increase the likelihood of municipalities developing a strategic orientation for collaborative governance initiatives, this does not seem to translate into a stronger likelihood of retaining decision-making power in public-private partnerships (H8). This disconnect suggests that while collaborative platforms may support alignment through strategic orientations, this does not automatically prevent dominant actors from exercising control over collaborative processes. Instead, as Ansell et al. (2025) and Wang and Ulibarri (2025) caution, strategy can potentially be instrumentalized to legitimize positions driven by self-interest rather than ensuring equity.

5.1.5 | Monitoring

Collaborative platforms are expected to facilitate the implementation of monitoring practices in collaborative governance arrangements by enabling transparency, learning, and accountability (see Bianchi 2022; Prasad et al. 2021). However, our findings suggest that this role may be overstated. While collaborative platforms are associated with an increased likelihood of municipalities developing a strategic orientation (H4), they do not appear to influence whether monitoring systems are adopted (H5). This disconnect between strategy formulation and monitoring implementation highlights a persistent challenge in governance theory: that strategic intent does not necessarily translate into operational implementation (Hitt et al. 2017; Tawse and Tabesh 2021).

This limitation raises broader concerns about the capacity of collaborative platforms to strengthen accountability within collaborative governance arrangements. Accountability, as conceptualized in this literature, refers to the responsiveness of decisions and outcomes to relevant stakeholders, including partners in the collaboration (S. Lee and Ospina 2022). However, as S. Lee (2021) points out, actors involved in collaborative initiatives often prioritize accountability to their home organizations over the collective, leading to conflicting commitments. Our findings suggest that collaborative platforms might not be able to help resolve this tension. The absence of a significant effect on monitoring adoption indicates that platforms may not be effective in fostering mechanisms that hold participants accountable to the shared goals of the collaboration.

This concern is further reinforced by our findings on decision-making power (H8), which indicate that platforms may not effectively prevent imbalances in influence, particularly in public-private partnerships. In such cases, dominant private actors may steer collaborative processes toward their own objectives while evading accountability to the broader group. Without robust monitoring systems in place, collaborative platforms may inadvertently provide cover for these actors to pursue self-interested goals under the guise of collective action.

Moreover, even when monitoring frameworks are introduced, our findings suggest that collaborative platforms may not mitigate the influence of power asymmetries on how these systems are designed and applied. As Leskaj (2017) and Robinson et al. (2020) observe, stakeholders often differ in their preferences for monitoring tools, indicators, and goals; for example, they could range from conceptual evaluations of governance effectiveness to more instrumental policy outcomes. These

methodological disagreements, combined with unequal decision-making power, can skew the development of monitoring systems toward the priorities of dominant actors (Torfing 2012). Therefore, rather than resolving such tensions, collaborative platforms may allow these imbalances to shape both the design and purpose of monitoring in ways that reinforce existing hierarchies.

5.1.6 | Vertical and Internal Coordination

Our findings indicate that collaborative platforms are associated with an increased likelihood of vertical coordination—municipal governments and higher levels of government—and internal coordination—departments, agencies and units in the municipal government. However, theses likelihoods are not necessarily greater than in municipalities without these platforms, many of which report comparable or even higher levels of coordination. This ambiguity raises questions about the potential contribution of collaborative platforms to vertical and horizontal integration within collaborative governance arrangements.

This view is reinforced by Reardon et al. (2022), who examine the use of Special Purpose Vehicles (SPVs) in India's Smart Cities Mission. While SPVs were introduced as collaborative platforms to facilitate coordination between national and local levels, the authors argue that they primarily served to centralize control and bypass local governance structures. This example illustrates how the intended collaborative function of a platform can be undermined by a broader institutional design that prioritizes central oversight over shared decision-making.

Therefore, it may be more appropriate to assess vertical and horizontal coordination not solely through the presence or absence of collaborative platforms, but in relation to the broader institutional design of the multilevel governance system in which they are embedded (Ehnert et al. 2018). In some contexts, multilevel governance operates through clearly delineated jurisdictions with stable authority boundaries (e.g., national, regional, and local levels), while in others, jurisdictions overlap, and authority is shared more fluidly (Hooghe and Marks 2003). These structural differences might influence whether collaborative platforms are able, or even permitted, to support meaningful coordination across levels of government.

5.1.7 | Decision-Making Power

Our findings suggest that municipalities without a collaborative platform may be more likely to retain decision-making power when collaborating with private partners than those with one. This contrasts with expectations in the literature (see Klievink et al. 2016; Leach et al. 2013; Wachhaus 2017), where collaborative platforms are often presented as mechanisms that empower public actors and ensure they have sufficient authority in multi-stakeholder settings. Rather than uniformly enabling municipal control, our results point to the possibility that collaborative platforms may, in some contexts, weaken public decision-making power.

In collaborative governance, power is conceptualized in multiple dimensions. Purdy (2012) distinguishes between "power to," which enables mutual gains by supporting collective action, and "power for," which enhances the capacity of others to participate (altruistic gain). In contrast, Huxham and Vangen (2005) present the concept of "power over," reflecting self-serving behavior that prioritizes individual interests over shared objectives. These dimensions highlight the importance of power balance in collaborative governance processes and the risks associated with asymmetries.

As Kruhlov et al. (2024) and Choi and Robertson (2013) emphasize, stakeholders in collaborative forums often hold unequal formal and informal power, potentially allowing stronger private actors to power over public partners. Based on our data, this represents an imbalance that collaborative platforms may fail to counteract, and they may even reinforce private dominance. These power dynamics can jeopardize public value creation (Ran and Qi 2017, 2019).

Revisiting Ansell and Gash's (2008) concept of collaborative governance helps illuminate this risk. The authors underscore how starting conditions, identified as distributions of power, knowledge, and resources, shape collaborative trajectories. If collaborative platforms fail to mitigate asymmetries in these starting conditions, the resulting process may privilege dominant actors. In this light, our findings suggest that collaborative platforms may inadvertently become vehicles for self-interested behavior, rather than mechanisms for equitable collaboration (Kretschmer et al. 2022).This raises a critical question: how can collaborative platforms better promote shifts from "power over" to "power to" and "power for" dynamics, fostering more inclusive and balanced decision-making (Huxham and Beech 2008)?

5.2 | Practical Contributions

This study also offers several practical insights for policy makers and platform managers in municipal government engaged in smart city development and other collaborative governance initiatives.

First, our findings respond to the concern raised by Ojasalo and Tähtinen (2016) regarding the limited practical understanding of how collaborative platforms can support local governments. By examining the likelihood of specific collaborative governance functions being enhanced through the presence of CPDs, our study presents a more grounded and nuanced view of their practical utility. This helps counter overly optimistic assumptions and offers a clearer, evidence-informed view of what collaborative platforms may achieve and where their necessity remains uncertain. This clarity helps manage expectations, avoiding premature disillusionment with platform-based approaches to collaboration.

Second, our results help local governments make more targeted and context-sensitive decisions about whether and how to institutionalize collaborative platforms. CPDs were found to increase the likelihood of enhancing certain collaborative governance capacities, notably knowledge sharing and strategic orientation. For municipalities seeking to improve these dimensions in collaborative governance initiatives, CPDs may

serve as an effective institutional tool. However, in areas such as competence development, internal coordination, and vertical alignment, the findings were more ambiguous. The presence of a CPD did not consistently translate into higher likelihoods of improvement, indicating that CPDs alone may be insufficient. In these cases, alternative mechanisms or complementary institutional reforms may be required. Therefore, until more conclusive evidence becomes available, public managers are advised to critically evaluate their governance priorities and local institutional contexts before committing to platform-based models.

Third, our findings emphasize that establishing a CPD is not a panacea. Although platforms may contribute to selected collaborative practices, they are not sufficient to overcome deeper structural issues such as power imbalances in public-private partnerships or the lack of monitoring systems. As such, their introduction should be accompanied by deliberate efforts to build absorptive capacity, align strategic orientation with implementation capabilities, and embed mechanisms for accountability and learning. Municipal leaders should avoid assuming that formalizing collaboration through a CPD will automatically lead to more effective governance outcomes. Instead, CPDs should be treated as one component in a broader strategic approach to building capacity for collaborative governance.

5.3 | Limitations and Recommendations for Future Research

Despite the structured and rigorous approach of this study, several limitations should be acknowledged. These limitations point to important avenues for future research that can strengthen the empirical reach and further develop the scholarship on collaborative platforms and governance.

First, although our sample includes municipalities from most global regions (with the exception of Oceania), it is largely composed of responses from European cities. Consequently, the findings primarily reflect European governance contexts, which poses limitations to the applicability of our findings in other regions. Collaborative governance dynamics can differ significantly across regions due to variations in administrative traditions, institutional settings, political structures, and socioeconomic conditions. Future studies should address this limitation by expanding empirical coverage to include underrepresented regions or by conducting region-specific analyses. Replicating the study across diverse settings would improve the generalizability and external validity of our findings.

Second, while our study examines the likelihood of collaborative platforms influencing various collaborative governance dimensions, it does not explain the mechanisms through which these platforms operate. Understanding how and why collaborative platforms are associated with certain outcomes requires a more granular exploration of their organizational arrangements and operational practices. Future research could adopt qualitative or mixed-methods approaches, including in-depth case studies, to investigate these mechanisms. Additionally, examining the reasons behind the continued adoption of collaborative platforms despite their uncertain effectiveness, could shed light on underlying institutional logics or normative expectations that shape decision-making in public administration.

Third, while our findings suggest that collaborative platforms may not consistently enhance collaborative governance, the study does not explore what alternative institutional arrangements or tools might prove more effective. Future research should compare collaborative platforms with other governance models, such as networked partnerships, informal coalitions, or mission-oriented governance frameworks, to identify which structures are best suited to particular collaborative challenges, especially in complex urban settings.

Fourth, the smart city domain serves as the empirical focus of this study. Although this application domain offers a rich context for examining collaborative governance and platforms, the findings may not readily transfer to other policy areas where collaborative platforms are applied, such as health, education, innovation, and environmental management. Future studies could investigate whether the patterns observed in smart city initiatives hold across other sectors, or whether different collaborative governance logics and performance dynamics are at play.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Linking manufacturing digitalization and technological Innovation: The mediating role of dynamic capabilities

Weimin Chen [a], Haiyan Lu [b], Luca Mora [c,d,*], Ting Chen [a], Dominik Beckers [d], Mengyun Hu [b]

[a] Fuzhou University, School of Economics and Management, Fuzhou, People's Republic of China
[b] Newcastle University Business School, Newcastle upon Tyne, UK
[c] Edinburgh Napier University, The Business School, Edinburgh, UK
[d] Tallinn University of Technology, Academy of Architecture and Urban Studies & FinEst Centre for Smart Cities, Tallinn, Estonia

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ABSTRACT

Amid the expanding digital economy and the progression of Industry 4.0 initiatives, both industry professionals and academic researchers are increasingly focused on unraveling the mechanisms by which manufacturing digitalization drives technological innovation. Build upon the resource-based view and dynamic capability theory, this study develops a theoretical framework and proposes research hypotheses to investigate how manufacturing digitalization and dynamic capabilities influence technological innovation, with particular attention to product and process innovation. Analyzing survey data from 276 manufacturing firms located in the first national-level pilot cities for digital transformation in China, structural equation modeling results reveal that: (1) digitalization within manufacturing firms can significantly promote both product and process innovation; (2) dynamic capabilities play a mediating role in linking manufacturing digitalization with technological innovation. Specifically, dynamic capabilities partially mediate the relationship between manufacturing digitalization and process innovation, and serve as a full mediator in its impact on product innovation. These findings provide theoretical insights and practical implications, helping manufacturing firms better recognize the strategic value of digitalization and dynamic capabilities in enhancing technological innovation through digital transformation.

1. Introduction

Technological innovation is a cornerstone of competitive advantage in the manufacturing sector, enabling firms to improve operational efficiency, respond to dynamic market conditions, and sustain long-term growth. In the context of Industry 4.0, the increasing digitalization of manufacturing processes has introduced profound changes in how firms develop and implement innovation strategies. Digital technologies such as IoT, big data analytics, AI, and cyber-physical systems are reshaping production systems and organizational structures, offering new avenues for product and process innovation (Gillani et al., 2020; Hughes et al., 2022). Consequently, both academic and practitioner communities have shown growing interest in understanding how digital transformation contributes to innovation outcomes and firm performance.

Despite this growing interest, empirical findings remain inconclusive. On one hand, studies highlight the positive impact of digital transformation on innovation capabilities, market adaptability, and performance outcomes (Culot et al., 2020; Verhoef et al., 2021). On the other hand, several scholars point to a "digitalization paradox," whereby significant investments in digital technologies do not consistently lead to improved innovation or economic performance (Gebauer et al., 2020; Moschko et al., 2023). Structural rigidities, misaligned resource allocation, and lack of strategic alignment are frequently cited as barriers that inhibit the expected returns on digital investment (Mikalef & Gupta, 2021). These conflicting findings underscore a fundamental research debate: under what conditions, and through what mechanisms, does digitalization enhance technological innovation in manufacturing?

This debate is particularly salient in the manufacturing sector, where empirical studies remain limited and fragmented. Existing research predominantly focuses on large firms in advanced economies (e.g., Germany and China), often through case-based or conceptual approaches (Radicic & Petković, 2023; Sarbu, 2022; Wu et al., 2022).

* Corresponding author. Edinburgh Napier University, The Business School, Edinburgh, UK.
E-mail address: l.mora@napier.ac.uk (L. Mora).

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While these studies offer useful insights, they fall short in explaining how digitalization leads to technological innovation—particularly in terms of product and process innovation—and why some firms fail to realize innovation gains despite embracing digital technologies. Moreover, the majority of prior work treats digitalization as a uniform construct, without sufficiently unpacking the organizational mechanisms that convert digital investment into tangible innovation outcomes.

To address this gap, this study integrates the resource-based view (RBV) with dynamic capabilities theory (Teece, 2007) to develop a mechanism-based explanation of the digitalization–innovation link. While RBV explains the strategic value of digital resources, dynamic capabilities theory highlights the firm-level processes that enable these resources to be mobilized for innovation, such as sensing technological opportunities and seizing innovation potential, as well as reconfiguring resources. To the best of our knowledge, this theoretical integration has yet to be applied in manufacturing digitalization research, and it allows us to move beyond documenting positive associations and instead identify *how* and *why* digitalization fosters different types of innovation.

In the context of digital transformation, dynamic capabilities such as sensing technological opportunities (Li et al., 2018; Warner & Wäger, 2019). Several scholars have demonstrated that dynamic capabilities mediate the relationship between digitalization and performance outcomes (Capurro et al., 2022; Ferraris et al., 2019; Yang et al., 2023), yet empirical evidence remains scarce in the context of manufacturing innovation. Furthermore, little is known about whether these mechanisms operate similarly across different types of innovation, a distinction that is theoretically important for understanding the varied returns to digital investment.

Against this backdrop, this study addresses the following research question: *To what extent does manufacturing digitalization influence technological innovation and how do dynamic capabilities mediate this relationship?*

By answering this question, this study makes three key theoretical contributions. First, it provides theoretical integration by combining RBV and dynamic capabilities theory, offering a richer explanation of the digitalization–innovation link than either perspective alone. Second, it contributes contextual nuance by using firm-level data from China's first batch of national-level pilot cities for digital transformation: an emerging-economy setting that has been largely overlooked in the literature. Third, it advances mechanistic understanding by disentangling the effects on product versus process innovation and empirically testing the mediating role of dynamic capabilities, revealing when and how digital investments are most likely to yield innovation gains. Together, these contributions position the study to extend prior work (for example, Björkdahl, 2020; Buer et al., 2021; Matarazzo et al., 2021; Shao et al., 2024; Wei & Sun, 2021a, 2021b) by further clarifying theoretical mechanisms, expanding empirical contexts, and differentiating innovation types.

2. Literature review and hypothesis

2.1. Theoretical framework

2.1.1. The resource-based view

RBV conceptualizes firms as organic entities composed of resources and capabilities (Wernerfelt, 1984), and it has evolved into a core framework for explaining how firms gain a competitive advantage by effectively integrating resources and capabilities (Barney, 2001; Madhani, 2010). Within this theoretical framework, resources are not merely individual assets but are integrated and deployed through specific organizational structures and processes, forming unique capabilities. As these capabilities result from the combination and application of multiple resources within particular organizational processes, they tend to be distinctive and difficult for competitors to imitate, thereby providing firms with sustained competitive advantage (Peteraf, 1993). The resource-based view emphasizes that by effectively managing and leveraging their resources and capabilities, firms can achieve greater adaptability and innovation potential in uncertain and dynamic environments. Previous research has widely applied the resource-based perspective to explore the determinants of firm innovation performance, especially in the context of digital transformation (Bakar & Ahmad, 2010; Bresciani et al., 2021; Elia et al., 2021). These studies offer valuable insights into how resource endowments influence the outcomes of a firm's digitalization practices.

RBV offers a lens to understand how digitalization contributes to technological innovation by framing it as a strategic organizational resource (Guo et al., 2023). According to RBV, firms gain and sustain competitive advantage by possessing resources that are valuable, rare, and inimitable (Freeman et al., 2021). Digitalization—through integrated technologies such as advanced data analytics, Internet of Things (IoT), and cloud-based systems—exemplifies these characteristics. First, digital capabilities are valuable as they enable firms to process complex information, enhance production efficiency, and accelerate innovation cycles (Ahn et al., 2022). Second, they are rare, as not all firms possess the infrastructure, expertise, and strategic alignment needed to fully deploy and integrate digital technologies. Third, these capabilities are often inimitable due to their embeddedness in firm-specific processes, culture, and historical development paths, making replication by competitors difficult. Lastly, digitalization is non-substitutable in the sense that no other single resource offers the same potential for real-time responsiveness, cross-functional integration, and innovation enablement.

Therefore, digitalization should not be viewed solely as a set of tools or systems, but as a bundled resource that supports the reconfiguration and orchestration of other assets within the firm. As Elia et al. (2021) argue, firms that effectively leverage digital technologies to integrate and adapt internal and external resources are better positioned to achieve innovation-led competitive advantage. This perspective underscores the central argument of this study: that digitalization functions as a VRIN resource in manufacturing firms, offering a foundation for sustained technological innovation and long-term performance gains.

2.1.2. Dynamic capabilities theory

The dynamic capabilities approach has emerged as an extension of the resource-based view of the firm to encapsulate the evolutionary nature of firms' resources and competencies for the next organizational phase of development or for new challenges theyface (Teece et al., 1997). Dynamic capabilities theory constitutes a significant theoretical framework within strategic management, elucidating how organizations sustain competitive advantage in rapidly evolving environments. Initially introduced by Teece et al. (1997), the theory has since been further developed and extensively applied. Dynamic capabilities refer to a firm's ability to sense, seize, and reconfigure internal as well as external resources to address environmental changes, thereby facilitating ongoing innovation (Teece, 2007). This concept encompasses three principal dimensions. First, sensing entails a firm's capability to perceive both opportunities and threats (Teece, 2007; Wu, 2010). Second, seizing pertains to the capability to capitalize on these opportunities by creating new products or offering new services (Wilden et al., 2013). Third, reconfiguring involves adjusting and reorganizing a firm's resource base and processes to align with changing market demands (Ellonen et al., 2009). This framework underscores the critical role of dynamic capabilities within corporate strategy and provides a theoretical foundation for explaining long-term business success in turbulent environments (Ringov, 2017). Through acute external sensing, internal learning, and flexible resource reallocation, firms can adapt to market shifts, innovate in response to challenges, and maintain their competitive advantage (Weerawardena & Mavondo, 2011).

Dynamic capabilities theory provides a valuable framework for understanding how manufacturing digitalization enhance technological

innovation through potential mediating mechanisms (Radicic & Petković, 2023; Savastano et al., 2022; Yang et al., 2023). For manufacturing firms to effectively boost their innovation through digitalization, cultivating dynamic capabilities is needed. The rapid evolution of digital technologies necessitates that companies quickly identify and respond to the opportunities and challenges these changes present (Warner & Wäger, 2019). As a result, manufacturing firms must develop strong market insights, particularly in their sensing capabilities. These capabilities can be improved with digital tools which help firms capture shifts in market conditions and technological trends (Matarazzo et al., 2021; Rialti et al., 2019). For example, by utilizing data analysis and intelligent systems, companies can monitor production processes in real-time, allowing for timely adjustments that enhance product innovation and streamline operational processes (Chirumalla, 2021). In contrast, firms that lack dynamic sensing capabilities may find it difficult to recognize and leverage these technologies, missing out on critical opportunities for innovation (Zhou et al., 2019).

To achieve technological innovation through manufacturing digitalization, manufacturing firms must develop effective resource-seizing and reconfiguring capabilities. Digitalization involves not only adopting new technological tools but also making significant adjustments and reorganizing current business processes, organizational setups, and resource allocations (Helfat & Raubitschek, 2018). This reconfiguration often requires complex organizational changes and technological adaptations. Only firms with strong dynamic capabilities can iteratively drive innovation throughout the digital transformation process (Yang et al., 2023). For instance, when implementing smart manufacturing systems, companies must integrate existing production lines and data systems while reallocating human resources and restructuring their organizations to effectively support technological innovation and optimize processes (Zhong et al., 2017). In this context, reconfiguration capabilities are essential, enabling continuous improvements in innovation performance during digital transformation (Warner & Wäger, 2019). Therefore, dynamic capabilities are necessary for leveraging supply chain digitalization to enhance innovation performance. They allow firms to quickly identify market changes, learn from past experiences, and flexibly adapt resource allocation, positioning them to seize opportunities, overcome challenges, and achieve both innovation and overall business success.

In summary, the integration of RBV and dynamic capabilities theory provides support for constructing a theoretical model that explains the impact of manufacturing digitalization on technological innovation, illustrated in Fig. 1. By combining these two theories, this study provides a comprehensive analysis of how digitalization in the manufacturing sector influences technological innovation and explores the potential mediating role of dynamic capabilities in this relationship.

2.2. Research hypothesis

2.2.1. Manufacturing digitalization and technological innovation

2.2.1.1. Manufacturing digitalization. Manufacturing digitalization encompasses the comprehensive incorporation of advanced digital technologies into multiple facets of manufacturing sector, leading to more efficient, flexible, and intelligent production and management processes (Gillani et al., 2020; Kamble et al., 2023). Key technologies driving this transformation include big data, IIoT, AI, cloud computing, and digital twins (Frank et al., 2019). These innovations enable real-time data gathering, analysis, and feedback, allowing manufacturering fitms to optimize production processes, improve resource utilization, and make informed decisions. Manufacturing digitalization goes beyond simply automating traditional equipment; it represents a complete digital transformation of the entire production system (Zangiacomi et al., 2020). For instance, smart monitoring systems can track the status of production lines, predict maintenance needs, enhance production continuity, and reduce downtime (Frank et al., 2019; Liu et al., 2023).

Manufacturing digitalization allows companies to react promptly to fluctuations in market demand, enabling personalized customization and limited-scale production while maintaining the efficiencies of mass production (Jones et al., 2021). This increased flexibility greatly enhances a firm's ability to adapt to market dynamics. Additionally, digitalization promotes supply chain collaboration and comprehensive lifecycle management by breaking down information silos, which leads to more effective cooperation and innovation (Culot et al., 2020). Therefore, the digital transformation of manufacturing not only redefines traditional production models but also initiates a comprehensive shift from product design to supply chain management, creating new competitive advantages and opportunities for innovation (Szalavetz, 2019; Ullah et al., 2024).

2.2.1.2. Technological innovation. Technological innovation involves the adoption of novel technologies, processes, or equipment aimed at improving products or production methods (Radicic & Petković, 2023). This ultimately strengthens an organization's competitive edge and adaptability within the marketplace (Usai et al., 2021). Technological innovation is generally classified into two primary types: product innovation and process innovation (Gurhan et al., 2011; Radicic & Petković, 2023). Product innovation refers to developing entirely new products or enhancing existing ones to improve their functionality and performance, with the goal of better addressing current market needs or even generating new demands (Ullah et al., 2024). This type of innovation encompasses the integration of emerging technologies, design enhancements, and material advancements, all of which are intended to boost product competitiveness and improve the overall user experience (Chaudhuri et al., 2024).

Process innovation involves the introduction of new or significantly improved production methods, manufacturing processes, or delivery systems that lead to greater efficiency, lower costs, and improved product quality. This innovation not only focuses on enhancing the technical aspects of production but also integrates new technologies, optimizes resource utilization, and continuously improves operational workflows. Research indicates that process innovation often leverages automation, intelligent systems, and data-driven strategies to better allocate and manage production resources, ultimately driving operational efficiency (Jianing et al., 2024; Jin et al., 2024). In the context of Industry 4.0, process innovation increasingly incorporates advanced digital technologies, such as automation, robotics, IIoT, cloud computing, and big data analytics. These technologies enable firms to streamline production processes, enhance real-time decision-making, and improve product consistency (Radicic & Petković, 2023). In essence, process innovation is about transforming the underlying processes that guide production and service delivery, ensuring that they become more agile, responsive, and cost-effective. By leveraging these innovations, firms can not only enhance their operational efficiency but also create

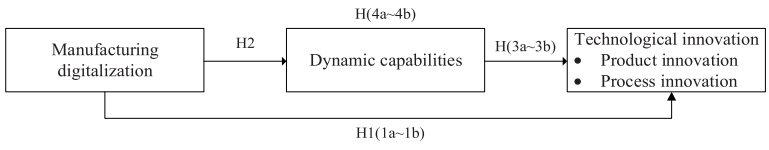

Fig. 1. Theoretical model.

more flexible and scalable systems capable of adapting to rapidly changing market demands and technological advancements.

2.2.1.3. The direct impact between manufacturing digitalization and technological innovation. Manufacturing digitalization directly influences technological innovation by enhancing a firm's key resources, which are critical for driving innovation. The resource-based view suggests that firms gain a competitive advantage by leveraging valuable, rare, and difficult-to-imitate resources (Barney, 1991). In this context, manufacturing digitalization may provide unique resources that significantly improve a firm's capacity to innovate technologically. First, manufacturing digitalization strengthens a firm's information processing capabilities. By improving the ability to collect and analyze data more efficiently, firms gain deeper insights into market dynamics, customer preferences, and emerging trends (Usai et al., 2021). This enhanced informational resource enables quicker identification of opportunities for innovation performance and supports more informed decision-making, facilitating the development of new products or processes (Gurhan et al., 2011). Second, manufacturing digitalization improves resource optimization. It allows firms to allocate and utilize both tangible and intangible resources—such as production assets, human capital, and organizational processes—more effectively (Ullah et al., 2024). This resource optimization leads to increased efficiency and cost savings, allowing firms to direct more resources toward innovation, thereby accelerating technological innovation performance (Jianing et al., 2024). Additionally, manufacturing digitalization fosters cross-functional integration, which plays a key role in innovation. By connecting departments such as R&D, production, and marketing, digital tools facilitate smoother collaboration and knowledge sharing (Cordeiro et al., 2023). This integration enhances coordination, accelerates the innovation process, and ensures that new ideas are effectively implemented throughout the organization (Radicic & Petković, 2023). In summary, manufacturing digitalization enriches critical resources—such as improved information processing, optimized resource utilization, and stronger cross-functional collaboration—that directly support technological innovation performance. These resources are distinctive, difficult for competitors to replicate, and essential for achieving sustained innovation and long-term competitive advantage. Building on these insights, the study proposes the following hypothesis.

H1. Manufacturing digitalization is positively linked to technological innovation.

Manufacturing digitalization facilitates product innovation by embedding intelligence and digital integration across all key stages of the production process, thereby enabling more efficient, precise, and responsive product development (Holmström & Partanen, 2014; Radicic & Petković, 2023). The deployment of intelligent equipment and real-time monitoring systems allows firms to enhance the control and visibility of production operations, making it easier to prototype and refine innovative product designs (Ivanov, 2023). For instance, the digitization of each production step creates a seamless feedback loop between product performance and production feasibility, allowing design teams to iterate rapidly with lower physical trial costs (Szalavetz, 2019). This capability is particularly beneficial for the development of novel products that require experimentation and fast adjustment (Agostini et al., 2020; Vilkas et al., 2022). Furthermore, the high level of informatization and interconnectivity enables manufacturers to support small-batch or customized production at scale, which is increasingly essential for developing differentiated and competitive products (Liu et al., 2023). These advanced capabilities reflect valuable and inimitable resources as conceptualized by the resource-based view (Barney, 1991), enabling firms to translate production system advancements directly into product-level innovations with high market potential (Frank et al., 2019). Therefore, the study proposes the following hypothesis.

H1a. Manufacturing digitalization is positively linked to improved product innovation.

Manufacturing digitalization leads to process innovation as it enhances operational efficiency, supports system standardization, and enables intelligent management of production-related data (Wei & Sun, 2021a, 2021b). The integration of intelligent equipment and the real-time digitization of critical production steps allow firms to monitor and adjust workflows with high precision (Duygan et al., 2023). These capabilities support the ongoing improvement of production processes, such as refining scheduling, enhancing throughput, and reducing variability—key elements for incremental and radical process innovations (Borangiu et al., 2019). Digitalized manufacturing environments enable companies to incorporate advanced tools and information systems more effectively (Zhou, 2013). For example, automated machines and MES systems reduce reliance on manual labor, increase process repeatability, and provide real-time data for continuous improvement (Schwab, 2017). These developments directly contribute to the updating of tools and IT applications within manufacturing operations (Kamble et al., 2023). From a resource-based perspective, the ability to repeatedly reconfigure and improve internal processes using embedded digital technologies represents a core source of competitive advantage and innovation (Elia et al., 2021). Moreover, the virtualization and simulation capabilities provided by digital technologies enable companies to test and optimize processes before actual production (Zhong et al., 2017). This allows firms to identify potential flaws in process designs and refine production paths, reducing risks and costs associated with process innovation (Kamble et al., 2023). Based on the resource-based view, the use of virtual simulations and testing tools can be viewed as the firm's investment in technological resources that improve process design and increase the speed and efficiency of innovation (Aral & Weill, 2007). Accordingly, the study proposes the following hypothesis.

H1b. Manufacturing digitalization is positively linked to improved process innovation.

2.2.2. The mediation role of dynamic capabilities

Dynamic capabilities enable organizations to maintain a competitive advantage in rapidly changing environments by sensing opportunities and threats, seizing them through timely action, and reconfiguring resources in response to change (Teece, 2007). These capabilities are typically expressed through three interconnected processes (Vogel & Guttel, 2013). First, the sensing capability involves scanning, interpreting, and anticipating external developments (Wu, 2010), requiring firms to possess strong learning mechanisms and market intelligence. Second, seizing refers to the ability to mobilize internal competencies and make strategic choices in response to perceived opportunities or threats (Yang et al., 2023). Third, reconfiguration emphasizes transforming and realigning organizational resources and routines to meet evolving demands (Matarazzo et al., 2021), which is vital for innovation and resilience under uncertainty (AL-Khatib et al., 2024). As firms navigate dynamic environments, these capabilities allow for continuous innovation, operational agility, and sustained competitive advantage (Eslami et al., 2024). In the context of manufacturing, the effective deployment and reorganization of information-related resources are essential to meet increasing demands for transparency and supply chain responsiveness (Savastano et al., 2022).

Digitalization plays a critical role in reinforcing these dynamic capabilities. By embedding real-time monitoring, intelligent systems, and advanced analytics across production stages, manufacturing firms enhance their ability to sense environmental changes. Digital platforms improve end-to-end supply chain visibility, facilitating deeper insights into market shifts, customer preferences, and resource availability (Abou-Foul et al., 2023). This transparency strengthens firms' ability to detect and interpret early warning signals—an essential condition for dynamic sensing (Savastano et al., 2022). Moreover, digital tools accelerate firms' seizing capacity by enabling rapid integration of new technologies, knowledge, and business models. Highly digitalized

environments support faster internalization of innovation through updated routines and real-time decision-making (Li et al., 2022; Mikalef & Gupta, 2021). Enterprise systems and data infrastructure also improve strategic responsiveness by translating external information into actionable internal learning. Finally, digitalization enhances reconfiguration by enabling agile adjustments in production setups, labor deployment, and strategic operations. Smart manufacturing technologies facilitate flexible adaptation to disruptions through the rapid reallocation of resources (Lin et al., 2020), allowing firms to respond efficiently to uncertainties and shocks (Felsberger et al., 2022; Ghosh et al., 2022).

Taken together, these digital capabilities actively support and amplify the firm's dynamic capabilities by enabling more effective sensing, accelerated seizing, and agile reconfiguring. Thus, digitalization does not merely support operations; it forms an integral resource base for sustaining innovation and adaptability. Building on this conceptual foundation, the study advances the following hypothesis.

H2. Manufacturing digitalization is positively linked to improved dynamic capabilities.

Dynamic capabilities theory posits that within a fast-evolving environment, a company's competitive advantages are likely to be short-lived (Teece, 2007). To effectively address opportunities and challenges, manufacturing firms must either continuously or unexpectedly disrupt the status quo, thereby achieving sustainable enhancements in innovation performance (Cordeiro et al., 2023). Dynamic capabilities foster technological innovation, encompassing both product and process innovations, through several mechanisms. First, the sensing function of dynamic capabilities empowers companies to recognize and seize rapidly emerging technological opportunities within the market (Zhou et al., 2022). Recent research indicates that by leveraging technologies, companies can more precisely detect shifts in market demand and technological trends, thereby uncovering potential avenues for innovation (Teece, 2010). Second, the seizing aspect of dynamic capabilities enables firms to rapidly integrate resources and engage in R&D (Wu, 2010). Sawers et al. (2008) noted that dynamic capabilities facilitate the efficient allocation of technology, capital, and human resources, which is crucial for the successful execution of both product and process innovations. Third, dynamic capabilities encourage cross-departmental collaboration and knowledge sharing, which is particularly vital for complex innovation projects (Cordeiro et al., 2023). Effective coordination among R&D, production, and marketing departments is essential. Helfat and Raubitschek (2018) emphasized that strong internal collaboration and knowledge integration enable firms to transform technological innovations from concept to reality, thereby supporting successful product development. Fourth, dynamic capabilities enhance an organization's capacity to respond to technological advancements and market shifts. Teece et al. (2016) argued that dynamic capabilities allow firms to refine their innovation strategies amid uncertainty, enabling swift responses to technological advancements and shifting market demands, which ensures the ongoing progression of process innovation. Finally, dynamic capabilities bolster organizational learning, assisting firms in accumulating knowledge and improving innovation efficiency in an ever-evolving technological landscape (Cordeiro et al., 2023). Zollo and Winter (2002) explained that through repeated learning and innovation practices, firms continuously refine and enhance their innovation processes, thereby securing long-term success in technological innovation. In light of the above analysis, this study proposes the following hypothesis.

H3. Dynamic capabilities are positively linked to technological innovation (a. product innovation; b. process innovation).

The digitalization of manufacturing serves as a catalyst for technological innovation while also enhancing an organizational dynamic capabilities, ultimately promoting both product and process innovation. Firstly, manufacturing digitalization considerably improves a firm's ability to analyze market trends and technological changes (Hao et al., 2023). In this way, by leveraging the sensing mechanisms inherent in dynamic capabilities, companies can monitor market demand (Zhou et al., 2022), technological advancements, and competitive conditions in real time, thereby enhancing their ability to identify innovation opportunities (Ullah et al., 2024). Radicic and Petković (2023) found that digital technologies allow firms to detect market shifts with greater precision, which supports new product development. This aligns closely with the sensing aspect of dynamic capabilities, enabling companies to remain agile in technological innovation and driving both new product development and the optimization of production processes (Chirumalla, 2021). Secondly, as AL-Khatib et al. (2024) noted, dynamic capabilities allow companies to efficiently integrate resources and technology through digital tools, improving the effectiveness of new technology applications. Digital platforms and smart manufacturing technologies enable organizations to structure R&D teams with greater flexibly (Gillani et al., 2020). This flexibility in resource allocation and integration is vital for fostering product innovation.

Thirdly, manufacturing digitalization enhances cross-departmental collaboration and knowledge sharing, thereby driving process innovation. Helfat and Raubitschek (2018) observed that cross-functional collaboration mechanisms within dynamic capabilities are further fortified in a digital environment. Smart manufacturing platforms facilitate real-time information sharing among R&D, production, and supply chain departments, promoting coordinated innovation efforts (Lin et al., 2020). This collaboration accelerates process optimization and innovation, enabling companies to become more flexible and efficient in production while responding rapidly to market changes (Chirumalla, 2021). Furthermore, dynamic capabilities expedite technological innovation by enabling agile resource allocation and strategic adjustments. In the context of manufacturing digitalization, dynamic capabilities leverage smart manufacturing systems and automated production lines to swiftly implement new technologies (Ghosh et al., 2022). Digital tools facilitate rapid prototyping during R&D, while automation accelerates experimentation and testing, thereby reducing the time required for new technology development (Yang et al., 2023). Zangiacomi et al. (2020) further emphasizes that digital technologies assist companies in simulating and optimizing production processes in real-time. This capability allows firms to quickly reconfigure production systems and resources in response to market changes (Wu, 2010), thereby fostering process innovation.

Recent work indicates that dynamic capabilities, in conjunction with digital technologies, significantly enhance a firm's responsiveness and agility within the field of technological innovation (AL-Khatib et al., 2024; Li et al., 2022; Yang et al., 2023). Matarazzo et al. (2021) assert that dynamic capabilities operationalized through the processes of sensing, seizing, and reconfiguring resources, empower organizations to navigate uncertain and complex market environments. In this context, digital technologies play a pivotal role by supporting these dynamic processes, allowing manufacturing firms to recalibrate their strategies and operations to align with emerging technological trends. This integration of digital technologies with dynamic capabilities facilitates a more fluid and effective innovation process, driving both product and process innovation performance (Wei & Sun, 2021a, 2021b). Building on the insights discussed above, this study proposes the following hypothesis.

H4. Dynamic capabilities mediate the link between manufacturing digitalization and technological innovation (a. product innovation; b. process innovation).

3. Methodology

3.1. Survey instruments

A questionnaire approach was utilized to collect the required information for testing the research hypotheses. To guarantee the reliability

and validity of the measurement instruments, three steps were undertaken. Initially, a thorough examination of relevant literature was performed to select authoritative scales previously utilized in both domestic and international studies. These scales were subsequently adjusted to fit the emphasis of the ongoing research, resulting in the initial version of the questionnaire. Second, a "back-translation" procedure was employed to translate the English scales, ensuring the accuracy of wording and expressions within the questionnaire. Two doctoral students specializing in operations and supply chain management, who had completed their studies in the United Kingdom, were invited to participate in this process. The original scales were first translated into Chinese. One doctoral student then transformed the Chinese version into English, while the other translated this English draft back into Chinese. This back-translation process ensured that the translated scales closely matched the content of the original questionnaire. Third, to minimize potential ambiguities or leading questions in the survey, the finalized version of the questionnaire was reviewed and discussed with the two doctroal students, leading to initial revisions. In alignment with the study's background and objectives, feedback was solicited from two senior scholars regarding the clarity and phrasing of the questionnaire. Additionally, five senior managers and IT department heads from companies not involved in the subsequent survey were invited to evaluate the questionnaire. As a result, further adjustments were made based on their feedback to guarantee that those questions were straightforward and easily understandable, culminating in the final version of the survey. In addition, to ensure conceptual clarity for respondents, we explicitly defined key constructs in the questionnaire. Specifically, the construct of manufacturing digitalization was described to respondents as the integrated application of multiple digital technologies, including AI, the IIoT, cloud platforms, automation, robotics, cloud computing, and big data analytics. The terms "intelligentization" and "informatization" used in the measurement items were thus understood by respondents to reflect the practical use of these technologies in production. This clarification ensures consistency between our theoretical framework and the operationalization of key constructs.

This study investigates six variables. The control variables include firm age, firm size, and firm ownership. Manufacturing digitalization serves as the independent variable, while dynamic capabilities act as the mediating variable. Technological innovation is identified as the dependent variable. Table 1 provides the definitions and explanations for each variable.

Manufacturing digitalization involves evaluating the extent to which firms are adopting digital technologies at different stages of the manufacturing process (Gbadegeshin, 2019; Wei & Sun, 2021a, 2021b). To this end, six assessment items were developed. Four of these items concentrate on data availability and assess the extent of real-time monitoring for every critical phase of manufacturing using smart manufacturing technologies. The remaining two items gauge the degree of connectivity and information integration across the manufacturing workflow.

Table 1
Definitions and explanations of the variables.

Variables	Variable name	Definition and explanation
Control variable	Firm Age	The number of years since the company was established.
	Firm Size	The total workforce size of the company.
	Firm ownership	The ownership type of the firm (e.g., state-owned, private, foreign or joint ventures).
Independent variable	Manufacturing digitalization	The comprehensive integration of advanced digital technologies into multiple facets of manufacturing aims to enhance the efficiency, flexibility, and intelligence of production and management processes.
Mediating variable	Dynamic capabilities	The firm's higher-order ability to sense, integrate, reconfigure, and allocate internal and external resources to adapt to dynamic environmental changes.
Dependent variable	Technological innovation	The process of developing new products, or production processes, or improving existing ones, through the application of new technologies, and methods.

In line with Wu (2010), this study adopts a unidimensional construct to measure dynamic capabilities, integrating the three foundational dimensions proposed by Teece (2007): sensing, seizing, and reconfiguring. While dynamic capabilities are often conceptualized as a multidimensional construct in theory, prior empirical work has operationalized it as a single construct that captures the firm's overall ability to sense opportunities and threats, seize them through timely resource mobilization, and reconfigure internal structures in response to change. Participants were asked to evaluate the dynamic capabilities present in their organizations. For example, one question was, "We frequently scan the environment to identify new business opportunities." Responses to these items were assessed on a five-point Likert scale, with response options varying from 1 (strongly disagree) to 5 (strongly agree).

The nine measurement items related to technological innovation were derived from research conducted by (Gurhan et al., 2011) and belong to two dimensions: product innovation and process innovation, with each dimension consisting of three items. Respondents were asked to assess the significance of the enhancement in technological innovation following the implementation of manufacturing digitalization. The extent of each performance indicator was evaluated using a five-point scale ranged from 1 (very low) to 5 (very high). The results of the first-order confirmatory factor analysis indicate that the two-factor model fits the data well: $\chi^2(87) = 169.385$, $p < 0.01$, CFI = 0.972, TLI = 0.966, RMSEA = 0.050. These findings suggest that product innovation and process innovation exhibit good discriminant validity.

Control variables utilized in this study were primarily derived from insights obtained through interviews with industry managers throughout the creation of the survey instrument. We identified firm age (the duration of operation), size (the number of employees), and ownership as control variables to mitigate their confounding effects on the dependent variables. To be specific, firm age was determined using the official establishment date of the surveyed company. Firm size was calculated by taking the base-10 logarithm of its total employee count, represented as firm size = lg (total number of employees). Ownership was categorized into three distinct classifications: state-owned, privately-owned, and foreign or joint ventures, represented by three dummy variables.

3.2. Data collection

This research utilized a questionnaire-based approach for empircal data collection. To guarantee the authenticity, representativeness, and completeness of the data, we implemented strict controls throughout every stage of the survey process. Prior to conducting fieldwork, we meticulously revised and refined the questionnaire's design and wording to ensure it accurately reflected the research objectives and significance. During the survey, we clearly communicated the study's purpose to participants and assured them that their responses would remain anonymous. This approach fostered a voluntary participation experience, alleviating concerns and enhancing the reliability and credibility of the responses.

The focus of this study on Chinese manufacturing firms is mainly due to China's prominent role as one of the leading manufacturing powers globally (Yang et al., 2023; Zheng et al., 2024). In recent years, the Chinese government has strongly prioritized the digital transformation of the manufacturing sector and the Industry 4.0 agenda, setting strategic goals such as "smart manufacturing" and "Made in China 2025". The central government has actively promoted the creation of policies and regulations conducive to digitalization, alongside initiating various pilot projects to advance the digital transformation process (Zheng et al.,

2024). These efforts provide rich samples and data for exploring how digitalization in manufacturing contributes to technological innovation. Overall, China's manufacturing digital transformation holds considerable practical significance and serves as a highly representative case globally. Studying Chinese manufacturing firms allows for a deeper understanding of how digitalization fosters technological innovation, offering valuable insights for the digital transformation of manufacturing sectors in other countries and regions.

In August 2023, China's Ministry of Industry and Information Technology announced the first batch of national-level pilot cities for digital transformation, aiming to accelerate corporate digitalization, enhance digital capabilities, and promote the deep integration of the digital economy with the real economy. Thirty cities, including Beijing, Shanghai, Suzhou, Hangzhou, and Guangzhou, were designated as pilot areas for this initiative. As a result, this study focuses on manufacturing firms within these designated regions that have either implemented or actively participated in digital transformation programs, making them the target for data collection. These firms possess extensive experience in applying and executing digital practices, having implemented various digital solutions across different facets of their operations. Their involvement in digital transformation initiatives spans areas such as production optimization, data analytics, and supply chain management, which has provided them with valuable insights into the challenges and opportunities of digitalization in the manufacturing sector. To minimize systemic bias and increase the representativeness of the sample, we included a diverse range of firms, including state-owned, private, and foreign or joint ventures. The study specifically targets mid-to senior-level managers who are familiar with their organization's digital work and overall operations. These managers are directly involved in the strategic and technological aspects of digital transformation in manufacturing, providing valuable insights into the process. Local governments in thirty targeted cities provided a list of 2534 manufacturing firms with contact information and a support letter, with the assistance of relevant industry associations. Considering that different types of manufacturing firms in China exhibit distinct characteristics and experiences during the digitalization process, we initially categorized these firms into three groups based on their ownership structure, including 745 state-owned, 1325 private, and 464 foreign-invested or joint venture. We employed a stratified sampling technique to randomly select a total of 600 companies from the three groups as the target sample.

In terms of questionnaire distribution, three primary methods were employed, that is, email surveys, postal mail, and on-site visits. Throughout the process, we emphasized the academic intent and importance of the survey to the respondents and assured them that their responses would remain confidential in order to enhance the reliability and credibility of the data. Questionnaires were distributed to 600 potential respondents from February and April 2024. After contacting by email, a questionnaire was sent out along with a prepaid return mail envelope. Besides, a website link was included in each questionnaire for respondents to complete an online survey. A total of 237 completed questionnaires were received during this round. To further increase the sample size, reminder emails were sent in May 2024, and follow-up calls were made to all non-respondents, with on-site visits conducted to encourage completion and submission of the questionnaires. An additional 45 responses were collected in this follow-up round. A total of 282 completed questionnaires were obtained across two rounds of data collection. Of these, 241 were returned via email and online mailing, 24 were collected through in-person visits, and 17 were returned by postal mail. After excluding questionnaires with more than six unanswered or incomplete sections, 276 useable responses were retained, resulting in an effective response rate of 46 %. Table 2 provides a summary of the descriptive information about the surveyed manufcturing firms, including details on their establishment year, size and ownership structure.

Table 2
Profile of sample firms ($N = 276$).

Category	Sample	Percentage (%)
Firm age (years)		
Less than 3	16	5.80
3-10	97	35.14
11-30	126	45.65
More than 30	37	13.41
Size (employees)		
Less than 201	58	21.01
201-500	78	28.26
501-1200	46	16.67
More than 1200	94	34.06
Ownership		
State-owned	79	28.62
Private	160	57.97
Foreign or joint ventures	37	13.41

3.3. Assessment of measurements and model fit testing

To validate the measurement instruments for manufacturing digitalization, dynamic capabilities, and technological innovation, confirmatory factor analysis was conducted. Tables 3–5 present the factor items alongside their respective factor loadings, all of which surpass the suggested minimum of 0.70, with values ranging from 0.791 to 0.931. Furthermore, Cronbach's alpha for all factors is above 0.70, demonstrating that the questionnaire has strong reliability. Each construct's composite reliability (CR) value surpasses 0.80, indicating robust internal consistency. Additionally, the average variance extracted (AVE) for each variable is above the 0.50 benchmark, supporting good convergent validity.

To assess the effectiveness of the four-factor model—comprising manufacturing digitalization, dynamic capabilities, product innovation, and process innovation—in providing an optimal fit and establishing discriminant validity between the variables, this study performed a comparative analysis of the fit results from various multi-factor models that include these critical components, as illustrated in Table 6. The findings indicate that the four-factor model provides the optimal fit for the sample data, thereby substantiating the assertion that the measurement scales for the constructs exhibit robust discriminant validity.

Table 7 further illustrates that the correlation coefficients between each pair of variables fall below the square root of their respective AVEs, thus confirming discriminant validity. To evaluate the model's goodness-of-fit indices (GFI), multiple criteria were applied. As presented in Tables 3–5, these indices for the three measurement models all meet or exceed the standards set by (Hu & Bentler, 1999). Additionally, CFA results indicate a satisfactory overall fit for the measurement model ($\chi^2(98) = 147.298$, CFI = 0.979, TLI = 0.975, IFI = 0.979, RMSEA =

Table 3
Reliability, validity, and GFI of manufacturing digitalization.

Item description	Loadings	S.E [a]	t-value
Manufacturing digitalization (α[b] = 0.931, CR = 0.931, AVE = 0.693)			
Firms manufacturing equipment is highly intelligent.	0.875***		
Firms use intelligent equipment to monitor each step of the manufacturing process in real-time.	0.869***	0.067	14.880
The informatization degree of firms' manufacturing process is very high.	0.789***	0.067	17.066
All crucial steps in firms' manufacturing processes have been digitized.	0.808***	0.064	17.226
The data of each manufacturing step can be interconnected in real-time.	0.823***	0.066	15.775
The manufacturing process is integrated by intelligent and informationalized means.	0.829***	0.068	15.941
GFI: $\chi2(9) = 17.347$, CFI = 0.993, TLI = 0.989, IFI = 0.993, RMSEA = 0.058			

[a] Standard error.
[b] Cronbach's alpha. ***$p < 0.001$.

Table 4
Reliability, validity, and GFI of dynamic capabilities.

Item description	Loadings	S.E [a]	t-value
Dynamic capabilities (α^b = 0.853, CR = 0.855, AVE = 0.596)			
Understand the product production process throughout the entire supply chain	0.754***		
Efficiently reallocate existing resources	0.752***	0.085	11.820
Incorporate the latest technologies or knowledge related to the company's development into internal learning programs, and apply them to business operations as quickly as possible	0.748***	0.090	11.762
Quickly sense and respond to changes in market prices, preferences, and other market trends	0.831***	0.081	12.836
GFI: $\chi2(2)$ = 5.300, CFI = 0.986, TLI = 0.989, IFI = 0.986, RMSEA = 0.080			

[a] Standard error.
[b] Cronbach's alpha. ***p < 0.001.

Table 5
Reliability, validity, and GFI of technological innovation.

Item description	Loading	S.E [a]	t-value
Product innovation (α^b = 0.791, CR = 0.795, AVE = 0.565)			
Develop new products with a higher degree of novelty than existing products	0.801***		
Develop new products that are more competitive in the market	0.783***	0.097	10.578
Develop new products with great market potential	0.663***	0.090	9.799
Process innovation (α^b = 0.798, CR = 0.798, AVE = 0.569)			
Update or improve production and business processes	0.761***		
Update or improve tools and equipment	0.770***	0.096	10.502
Update or improve the application of information technology	0.731***	0.091	10.318
GFI: $\chi2(8)$ = 15.975, CFI = 0.985, TLI = 0.972, IFI = 0.985, RMSEA = 0.058			

[a] Standard error.
[b] Cronbach's alpha. ***p < 0.001.

Table 6
Discriminant validity between the variables.

Model	χ^2	*Df*	RMSEA	RMR	CFI	TLI
Zero model [h]	2495.457	120	0.268	0.207	0.000	0.000
Four-factor model	**147.298**	**98**	**0.043**	**0.021**	**0.979**	**0.975**
Three-factor model [a]	358.223	101	0.096	0.053	0.892	0.871
Three-factor model [b]	399.382	101	0.104	0.066	0.874	0.851
Three-factor model [c]	348.943	101	0.094	0.050	0.896	0.876
Three-factor model [d]	603.650	101	0.135	0.065	0.788	0.749
Two-factor model [e]	586.098	103	0.131	0.074	0.797	0.763
Two-factor model [f]	614.375	103	0.134	0.081	0.785	0.749
Single-factor model [g]	1031.232	104	0.180	0.093	0.610	0.550

N = 276.
a Combine dynamic capabilities and product innovation into one latent factor.
b Combine dynamic capabilities and process innovation into one latent factor.
c Combine product innovation and process innovation into one latent factor.
d Combine manufacturing digitalization and dynamic capabilities into one latent factor.
e Combine dynamic capabilities, product innovation, and process innovation into one latent factor.
f Combine manufacturing digitalization, product innovation, and process innovation into one latent factor.
g All items belong to the same latent factor.
h In the zero model, there is no link among all measurement items.

0.043). Table 7 displays the means, standard deviations, as well as correlation coefficients for the main variables. Significant correlations between pairs of variables offer initial support for the hypotheses.

3.4. Non-response bias and common method bias

After brief communication with non-respondents, it was confirmed that there were no refusals to participate in the interview or complete the questionnaire due to issues with the questionnaire design or inconsistencies in the item statements. As a result, this study concentrates exclusively on the impact of the different survey periods on the final questionnaire responses. Adopting the approach proposed by Armstrong and Overton (1977), we used the two-sample *t*-test to determine whether a significant difference exists between the questionnaires collected from early (195) and late (81) responses. The *t*-test results of mean values for all constructs demonstrate that no significant difference exists between the groups (p > 0.05), as shown in Table 8. Therefore, non-response bias does not represent a problem in this study.

Since all these variables are sourced from the same questionnaire, a potential concern of common method bias that could lead to spurious correlations among them. To mitigate this issue, we performed Harman's single-factor test, following the approach established by (Podsakoff et al., 2003). We subjected all questionnaire items to unrotated principal component factor analysis. The finding that the first factor explains less than 50 % of the total variance suggests that common method bias is unlikely to be a major concern. In this study, the first factor accounted for 36.788 % of the total variance, falling comfortably below the accepted threshold, suggesting that no single factor dominates the variance. Additionally, we performed confirmatory factor analysis as part of Harman's single-factor test, which yielded a poor model fit with $\chi^2(104)$ = 1031.232, CFI = 0.610, TLI = 0.550, and RMSEA = 0.180. This result further supports the conclusion that the research data does not exhibit significant common method bias and is therefore suitable for further empirical analysis.

Table 7
Means, standard deviations, and correlation coefficients between the variables.

Variable	Mean	SD	1	2	3	4
1. Manufacturing digitalization	3.669	0.689	(0.832)[a]			
2. Dynamic capabilities	3.704	0.556	0.258**	(0.772)		
3. Product innovation	3.696	0.707	0.181**	0.343**	(0.752)	
4. Process innovation	3.734	0.649	0.440**	0.307**	0.328**	(0.754)

N = 276; **p < 0.01, *p < 0.05; [a] Square root of AVE reported along diagonal in italics.

4. Statistical analysis and results

4.1. The main effect test

We employed structural equation modeling to analyze the connections between manufacturing digitalization, dynamic capabilities, and technological innovation, utilizing AMOS 24.0 statistical analysis software. The structural equation model results demonstrate a robust alignment between the proposed theoretical model and the observed data: $\chi2(147)$ = 203.744, CFI = 0.979, TLI = 0.973, RMSEA = 0.037.

To test hypotheses H1a and H1b, this study constructs a structural equation model to evaluate the direct impact of manufacturing

Table 8
The *t*-test result of the non-response bias.

Group		N	Mean	S. D	F	Sig.
Manufacturing digitalization	early	195	3.638	0.693	0.002	0.967
	later	81	3.743	0.677		
Dynamic capabilities	early	195	3.696	0.538	0.269	0.604
	later	81	3.722	0.601		
Product innovation	early	195	3.607	0.716	0.234	0.629
	later	81	3.912	0.639		
Process innovation	early	195	3.640	0.649	0.858	0.355
	later	81	3.959	0.593		

digitalization on technological innovation, as illustrated in Fig. 2. The fit indices for the primary effect model satisfy the established criteria: $\chi^2(88) = 138.041$, CFI = 0.977, TLI = 0.969, and RMSEA = 0.045. These indices exceed the advised thresholds (Hu & Bentler, 1999), indicating an adequate model fit. Control variables were included into the structural model, with their residuals initially set to zero and factor loadings fixed at one, following the recommendations outlined by (Seibert et al., 2001). As demonstrated in Fig. 2, there is a significant and positive correlation between manufacturing digitalization and both product innovation ($\beta = 0.176$, $p < 0.01$) and process innovation ($\beta = 0.498$, $p < 0.001$). Therefore, these findings provide confirmation for H1a and H1b.

4.2. The mediating effect test

The causal steps approach was employed to test the mediating effect of dynamic capabilities in the relationship between manufacturing digitalization and technological Innovation. As shown in Table 9, manufacturing digitalization is significantly and positively associated with product innovation (M4, $\beta = 0.153$, $p < 0.05$) and process innovation (M8, $\beta = 0.402$, $p < 0.001$), respectively. Thus, H1ã1b are supported. Dynamic capabilities are positively influenced by manufacturing digitalization (M1, $\beta = 0.201$, $p < 0.001$) after entering the mediator. H2 receives statistical support. Dynamic capabilities are positively linked with product innovation (M5, $\beta = 0.411$, $p < 0.001$) and process innovation (M9, $\beta = 0.336$, $p < 0.001$) as well. Therefore, H3a and H3b are supported. However, the direct effect of manufacturing digitalization on product innovation (M6, $\beta = 0.075$, n.s) becomes non-significant, which implies that dynamic capabilities fully mediate the relationship between manufacturing digitalization and product innovation. Thus, H4a is fully supported. Meanwhile, the direct effect of manufacturing digitalization on process innovation (M10, $\beta = 0.357$, $p < 0.001$) is lessened but still significant, which implies that the effect of manufacturing digitalization on process innovation is partially mediated by dynamic capabilities. Thus, H4b is partially supported.

The Bootstrapping approach employs non-parametric sampling, eliminating the need to the assumption that the sample follows a normal distribution, thereby facilitating a more precise estimation of standard errors (Taylor et al., 2008). As a result, we adopted the Bootstrapping approach to provide additional confirmation of the mediation results related to dynamic capabilities, particularly the indirect effects present within the association between manufacturing digitalization and both product and process innovation. The Bootstrapping procedures conducted using AMOS 24.0 produced 95 % Bias-Corrected and Percentile confidence intervals, along with corresponding coefficients for each pathway, derived from 5000 bootstrap samples. An indirect effect is deemed significant once the confidence interval does not encompass zero (MacKinnon et al., 2007). As illustrated in Table 10, the direct effect of manufacturing digitalization on product innovation lacks significance (includes zero), while its effect on process innovation is significant (excludes zero) within the 95 % confidence interval. Additionally, the indirect effects through dynamic capabilities are significant as well (excludes zero). Consequently, H4 is further substantiated.

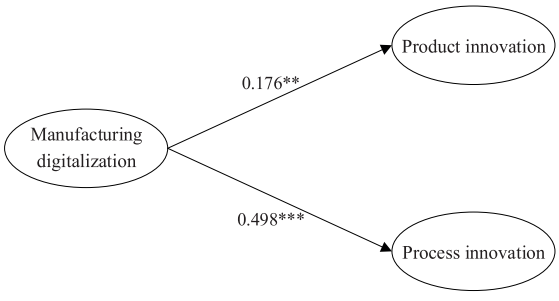

Fig. 2. Main effects test.

5. Discussion and implications

5.1. Main findings

Based on the resource-based view and dynamic capabilities theory, this study presents a conceptual framework that investigates the connection among manufacturing digitalization, dynamic capabilities, as well as technological innovation. Using a sample of 276 manufacturing firms from China's first national digital transformation pilot cities, the research explores how manufacturing digitalization impacts technological innovation and examines the mediating role of dynamic capabilities within this framework.

Empirical findings reveal a positive correlation between manufacturing digitalization and both types of technological innovation, indicating that proactive adoption of digital practices within manufacturing firms can substantially improve innovation outcomes. Such a finding challenges (Moschko et al., 2023), who argued that digital shifts could lead to unanticipated innovation failures, highlighting that digitalization's effects are more complex than previously suggested. This study, however, shows that when managed well, digitalization can accelerate innovation. This study also found that process innovation benefits the most from manufacturing digitalization, while product innovation demonstrates a relatively weaker positive effect. Such a finding partially extends the conclusions drawn by Wei and Sun (2021a, 2021b). Although the latter highlighted that digitalization in manufacturing supports green process innovation, they did not empirically investigate how supply chain digitalization affects other types of innovation, like product innovation. Our study validates and expands their findings, offering deeper insights into how digital practices in manufacturing not only enhance process innovation but also play a crucial role in fostering product innovation by improving design flexibility, accelerating development cycles, and enabling better alignment with market demands.

This study validates the mediating role of dynamic capabilities in the relationship between manufacturing digitalization and technological innovation, addressing a significant gap in the existing literature. While some previous works have discussed the potential impact of dynamic capabilities in conceptual discussions or case studies (Chirumalla, 2021; Okano et al., 2022; Warner & Wäger, 2019), empirical investigations into how dynamic capabilities mediate the link between digital transformation in manufacturing and technological innovation remain limited. Grounded in dynamic capabilities theory, this study develops a mediating effect model to analyze the role of dynamic capabilities in the relationship between manufacturing digitalization and technological innovation, providing an in-depth investigation into the various manifestations of dynamic capabilities in this context. The findings reveal that dynamic capabilities positively mediate the effect of manufacturing digitalization on technological innovation, with distinct mediating effects on different types of technological innovation, such as product and process innovation. These results not only enriches the theoretical framework of manufacturing digitalization and technological innovation but also offers new perspectives and insights for practical research in the field.

Our findings provide empirical evidence that dynamic capabilities partially mediate the relationship between manufacturing digitalization and process innovation. This result aligns with the work of Qi et al. (2024), who, in their literature review, highlighted that business process improvements driven by digital transformation largely depend on the organization's dynamic capabilities. Furthermore, our study extends and validates this perspective using a sample from the Chinese manufacturing sector. We suggest that manufacturing firms should fully leverage cutting-edge digital technologies, such as big data analytics, artificial intelligence, and the Internet of Things, to enhance their data

Table 9
The mediating effect test of dynamic capabilities (N = 276).

	Dynamic capabilities		Product innovation				Process innovation			
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Size	−0.006*	−0.006*	−0.005	−0.005	−0.002	−0.002	−0.007*	−0.006*	−0.005	−0.005
Firm year	0.060	0.034	0.204**	0.184**	0.179**	0.171**	0.167**	0.114*	0.146**	0.107*
State-owned	0.103	0.085	0.249	0.235	0.206	0.202	0.219	0.185	0.185	0.165
Private	0.157	0.112	0.359*	0.324*	0.294*	0.281*	0.197	0.108	0.145	0.082
Manufacturing digitalization		0.201***		0.153*		0.075		0.402***		0.357***
Dynamic capabilities					0.411***	0.388***			0.336***	0.226**
R2	0.027	0.088	0.055	0.077	0.157	0.162	0.045	0.223	0.126	0.257
F	1.907	5.179***	3.980**	4.516**	10.051***	8.658***	3.210*	15.462***	7.768***	15.489***
ΔR2	0.027	0.060	0.055	0.022	0.101	0.085	0.045	0.177	0.081	0.034
ΔF	1.907	17.796***	3.980**	6.345*	32.484***	27.179***	3.210*	61.601***	24.871***	12.368**

Note. ***p < 0.001, **p < 0.01, *p < 0.05.

Table 10
Mediating effect of dynamic capabilities.

Path	Coefficient	T value	Bootstrapping			
			Bias-Corrected 95 % CI		Percentile 95 % CI	
			Lower	Upper	Lower	Upper
Total effects						
Manufacturing digitalization→ Product innovation	0.182***	2.493	0.033	0.309	0.032	0.309
Manufacturing digitalization→ Process innovation	0.470***	7.100	0.357	0.632	0.354	0.630
Indirect effects						
Manufacturing digitalization→ Dynamic capabilities→Product innovation	0.114***	3.000	0.048	0.192	0.042	0.183
Manufacturing digitalization→ Dynamic capabilities→Process innovation	0.065	2.429	0.025	0.137	0.019	0.129
Direct effects						
Manufacturing digitalization→ Product innovation	0.068	0.901	−0.076	0.203	−0.074	0.205
Manufacturing digitalization→ Process innovation	0.406***	5.645	0.275	0.574	0.273	0.573

Number of Bootstrapping samples = 5000. *p < 0.05, **p < 0.01. ***p < 0.001.

analysis capabilities, thereby offering robust support for process innovation. Moreover, digital technologies enable continuous monitoring and feedback during production processes, promoting cross-departmental and cross-functional collaboration, which in turn enhances overall operational efficiency and further drives the deepening of process innovation.

Empirical findings indicate that dynamic capabilities serve as a full mediator in the connection between manufacturing digitalization and product innovation. This means the benefits stemming from manufacturing digitalization for product innovation can only be realized by improving dynamic capabilities. In this context, developing these capabilities is essential for manufacturing firms adopting digital practices. Our findings contrast with those of AL-Khatib et al. (2024), who argued that although dynamic capabilities facilitate product innovation, digital practices in manufacturing can sometimes directly drive product innovation through the application of technology or resource integration, without relying on complex dynamic capability development processes. This is because certain digital technologies, such as 3D printing, IIoT and AI, inherently possess high adaptability and innovation potential, enabling rapid creation of new products or improvements to existing ones, thereby directly driving technological change and product innovation. Our results emphasize the importance of cultivating dynamic capabilities to effectively leverage and navigate digitalization for product innovation. From the perspective of dynamic capabilities theory, dynamic capabilities encompass an organization's ability to reconfigure resources, adjust processes, and modify organizational structures in response to changing market environments. Without effective dynamic capabilities, firms may fail to fully capitalize on the innovative opportunities offered by digital technologies, potentially missing out on the value they could derive from applying such technologies (Liu et al., 2023; Warner & Wäger, 2019). For instance, while AI and big data can help firms extract valuable insights from vast amounts of data, without sufficient dynamic capabilities to adapt to changes in the flow of information, they will be unable to effectively contribute to product innovation.

5.2. Theoretical implications

In the context of Industry 4.0, by drawing on the RBV and dynamic capabilities theory, our findings expands the current understaidng of how digitalization in manufacturing firms fosters technological innovation, including both product and process innovations. First, we systematically analyze the relationship between manufacturing digitalization and technological innovation, revealing how digitalization influences various aspects of technological innovation. This analysis not only extends the theoretical findings on the impact of digitalization on technological innovation proposed by Gillani et al. (2020), Apostolov and Coco (2021), Urbinati et al. (2020), but also offers a noval theoretical perspective for understanding innovation performance in the digital transformation process. In particular, by integrating RBV and dynamic capabilities theory, our study responds to calls for mechanism-based explanations of digital transformation outcomes (Björkdahl, 2020), moving beyond purely correlational accounts to illuminate the capability-driven processes that enable digital resources to be translated into specific innovation outcomes.

Second, this study further clarifies how dynamic capabilities mediate the process through which manufacturing digitalization can drive technological innovation, enriching the theoretical debate regarding the relationship between dynamic capabilities and digital transformation. While existing literature extensively discusses the relationship between digitalization and technological innovation, most studies lack in-depth exploration of the critical role dynamic capabilities play in this process. By introducing dynamic capabilities as a mediating variable and guided by dynamic capabilities theory, this study provides empirical evidence that sheds light on the "black box" between manufacturing digitalization and technological innovation. This study extends the

conclusions of Matarazzo et al. (2021) and Shao et al. (2024) regarding the need for a mediating mechanism in the digitalization-innovation link. We find that the technological innovation improvements driven by manufacturing digitalization are not merely the result of direct effects; instead, dynamic capabilities play a crucial mediating role in this relationship. This finding underscores the importance of dynamic capabilities in transforming a firm's digital resources into innovation performance, thus facilitating technological innovation. Specifically, cultivating strong dynamic capabilities is essential for new product development driven by manufacturing digitalization. Our paper clarifies the distinct mediating roles that dynamic capabilities play between manufacturing digitalization and different types of innovation performance. In doing so, it complements prior studies (see Buer et al., 2021) by showing that, regardless of firm size or production environment, dynamic capabilities are a key internal mechanism through which digital tools produce differentiated innovation gains. Moreover, in line with Wei and Sun (2021a, 2021b), our results underscore that these mechanisms are particularly relevant for process innovation, where organizational structures and information-processing capacity amplify the benefits of digitalization. Terefore, our study fills the gap in the existing literature on how manufacturing digitalization promotes technological innovation through organizational dynamic capabilities while also strengthening and deepening research on the relationship between supply chain digitalization and innovation performance.

Third, as a significant emerging market, China's level of digitalization in manufacturing is still in the early stages compared to developed countries, and research on digital innovation performance remains largely exploratory. This study, based on the context of Chinese manufacturing, explores how digitalization specifically impacts different types of technological innovation, particularly product and process innovation, while further elucidating the mediating effect of dynamic capabilities in this process. The findings highlight the functions and value of manufacturing digitalization, while providing empirical evidence from an emerging market. By situating the analysis in China's first batch of national-level pilot cities for digital transformation, the study empirically examines the industrial transformation vision outlined by Zhou (2013), adding rare large-scale firm-level evidence from this policy-driven context. This contextual focus not only extends existing Industry 4.0 research – still dominated by advanced-economy cases – but also enables theorization on how emerging-market policy environments shape the capability–innovation pathway. This contributes innovative practices to the field of digital transformation research.

5.3. Managerial implications

Digital transformation serves as a crucial technological foundation for driving innovation within manufacturing firms (Sarbu, 2022). This study demonstrates a significant positive correlation between manufacturing digitalization and both product innovation and process innovation. Manufacturing firms should recognize that pushing for digital transformation is not only a necessary response to market changes but also a way to help businesses stand out in a competitive environment. Therefore, manufacturing companies should actively promote digital practices to replicate innovative solutions. Specifically, first of all, managers in manufacturing firms should prioritize investments in digital technology infrastructure, such as cloud computing, big data analytics platforms, and smart manufacturing systems. These technologies will provide the data support and real-time feedback necessary for accelerating product and process development (Radicic & Petković, 2023). Manufacturing firms should also continuously assess and optimize their existing digital resources and technology frameworks to ensure they are capable of supporting technological innovation. Second, managers should strengthen digital skills training for employees, particularly in areas such as data analysis, artificial intelligence applications, and automation technologies (Nicolás-Agustín et al., 2024). Only with the appropriate skills can companies fully leverage the potential of digital tools in innovation (Zheng et al., 2024). Finally, managers should drive the digital transformation of supply chains, utilizing digital optimization of information flow and logistics to enhance supply chain management. This will not only improve process efficiency but also promote product innovation, as the flexibility and collaboration of the supply chain can accelerate market feedback and product iteration (Schiavone et al., 2022). By implementing these specific management measures, manufacturing firms can leverage the advantages of digitalization to improve product quality, increase production efficiency, and thereby achieve continuous innovation while maintaining competitiveness.

On the other hand, dynamic capabilities act as a mediating mechanism that facilitates the transformation of digitalization into technological innovation within the manufacturing industry. According to dynamic capabilities theory, managers in manufacturing firms must proactively develop and enhance the organization's dynamic capabilities in order to effectively promote technological innovation (AL-Khatib et al., 2024). First, managers should focus on strengthening dynamic capabilities by establishing structured mechanisms for knowledge absorption and integration, particularly in areas such as digitalization strategies, technical standards, and other knowledge domains. These mechanisms enable firms to quickly absorb external new technologies and incorporate them with internal knowledge and resources, thereby facilitating product quality improvements and market penetration (Cordeiro et al., 2023). Second, managers should foster a culture of continuous learning and responsiveness within the organization to enhance the effectiveness of dynamic capabilities. This can be achieved through internal training programs, cross-departmental collaboration, and external partnerships (Zhou et al., 2022), which can raise employees'' awareness of digital technologies, particularly with regard to understanding technological risks in product innovation. The learning capability can be further strengthened through continuous product testing, iteration, and feedback mechanisms (Zollo & Winter 2002), which in turn drive the development of new products and technological improvements. Moreover, enhancing organizational flexibility, allowing the firm to quickly adjust production and product development processes, is also an integral part of dynamic capabilities. Managers can improve the firm's responsiveness by optimizing decision-making processes, streamlining internal communication, and strengthening cross-departmental collaboration (Warner & Wäger, 2019). This internal agility and responsiveness will help manufacturing firms maintain their innovative capacity throughout the digital transformation process, ultimately advancing technological innovation. In conclusion, managers should strategically focus on enhancing dynamic capabilities to ensure that the digital transformation within manufacturing firms effectively leads to a competitive advantage through technological innovation. Such process relies on critical dynamic capabilities actions, such as knowledge integration, organizational learning, and adaptability, to ensure a positive relationship between digital transformation and technological innovation.

6. Conclusions

Against the backdrop of China's ongoing digitalization efforts amid the Industry 4.0 revolution, this paper investigates how manufacturing firms in China leverage digitalization to foster technological innovation, grounded in an integrated perspective that RBV and dynamic capabilities theory. Specifically, it analyzes how dynamic capabilities act as a mediator in the connection between manufacturing digitalization and technological innovation. Utilizing questionnaire responses collected from 276 manufacturing firms within the first batch of national-level digital transformation pilot cities in China. Our structural equation modeling results indicate that, firstly, the promotion of digitalization within manufacturing firms leads to significant advancements in technological innovation, with a more pronounced effect on process innovation compared to product innovation. Secondly, the innovation

stimulated by digitalization is not solely attributable to its direct impact; dynamic capabilities also play a critical mediating role. Specifically, dynamic capabilities partially mediate the impact of manufacturing digitalization on process innovation and fully mediate their impact on product innovation in the manufacturing sector.

These findings make three theoretical contributions. First, they advance the integration of RBV and dynamic capabilities theory by providing a mechanism-based explanation of how digital resources are transformed into distinct innovation outcomes, answering calls for deeper theorization of the *how* behind digitalization's effects (Björkdahl, 2020). Second, they contribute contextual nuance by offering rare large-scale, firm-level evidence from an emerging-economy setting, extending Industry 4.0 studies still dominated by advanced-economy cases (Buer et al., 2021; Zhou, 2013). Third, they enrich mechanistic understanding by distinguishing between product and process innovation and showing that dynamic capabilities mediate these pathways differently, complementing prior work on process-oriented innovation mechanisms (Wei & Sun, 2021a, 2021b) and revealing when and how digitalization yields innovation gains. In doing so, this study extends and connects multiple strands of literature on manufacturing digitalization, technological innovation, and organizational capabilities.

By analyzing those mechanisms through which digitalization influences innovation in manufacturing firms, this study highlights the functions and tactical value of digital transformation. Moreover, it provides empirical insights from emerging markets, thereby enhancing the body of research on digitalization within manufacturing contexts.

Some limitations identified in this analysis warrant careful consideration in future studies. To begin with, the relationship between digitalization in manufacturing and technological innovation may be significantly influenced by industry-specific factors and sectoral segmentation. For example, the innovation trajectories pursued by the automotive industry during digitalization may differ from those of the textile and apparel industry. Additionally, industries may vary considerably in terms of resource integration, the degree of technological adoption, and market demand. To better understand the specific impact of digitalization on innovation, future research could incorporate these industry-specific factors and segmentation categories as control variables within the theoretical framework. This would help to reveal the differential impacts of digital transformation across industries. Moreover, cross-industry comparative studies could provide targeted practical guidelines for policymakers and business managers.

Secondly, as a cross-sectional study, this research does not capture the dynamic changes in innovation driven by digitalization within manufacturing firms over time. While cross-sectional data provide valuable insights into the current state, they fail to reveal the long-term effects and evolutionary processes of digitalization's impact on technological innovation. Future research could adopt longitudinal or dynamic models to assess the sustained changes and development of innovation performance before and after the implementation of digitalization, thereby offering a more comprehensive understanding of the long-term effects of digital transformation on technological innovation.

Lastly, while this study explores the mediating role of dynamic capabilities in the association between manufacturing digitalization and technological innovation, it does not delve into the specific impact of different types of dynamic capabilities (such as sensing, seizing, and reconfiguring capabilities) on innovation outcomes. Future research could further segment dynamic capabilities by analyzing how different types influence the relationship between digital transformation and technological innovation in various contexts. This is particularly relevant given evidence that different environmental and organizational settings (Buer et al., 2021) and different information-processing structures (Wei & Sun, 2021a, 2021b) may favor specific types of capabilities. Particularly, the role of dynamic capabilities may vary across different cultural backgrounds and organizational types. By refining this research, we can gain a deeper understanding of which types of dynamic capabilities effectively promote technological innovation in specific contexts, thereby providing more precise management recommendations for firms.

CRediT authorship contribution statement

Weimin Chen: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Haiyan Lu:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Luca Mora:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Ting Chen:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dominik Beckers:** Writing – review & editing, Writing – original draft. **Mengyun Hu:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The authors do not have permission to share data.

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Curriculum vitae

Personal data

Name:	Dominik Beckers
Date of birth:	19.02.1995
Place of birth:	Hamm, Germany
Citizenship:	German

Contact data

E-mail:	dominik.beckers@taltech.ee

Education

2021–2026	Tallinn University of Technology, PhD
2017–2019	Lund University, MSC
2018–2019	National Taiwan University, MSC
2014–2017	Utrecht University, BSC
2016–2017	University of Iceland, BSC
2013–2014	Utrecht University of Applied Sciences, BSC
2005–2013	Gymnasium Hammonense Hamm, High school

Language competence

German	Native
English	Fluent
Dutch	Basic
French	Basic

Professional employment

2021–2026	FinEst Centre for Smart Cities, Tallinn University of Technology
2021–2026	Urban Innovation Policy Lab, Edinburgh Napier University
2017–2024	Technopolis Group

Elulookirjeldus

Isikuandmed

Nimi:	Dominik Beckers
Sünniaeg:	19.02.1995
Sünnikoht:	Hamm, Saksamaa
Kodakondsus:	Saksa

Kontaktandmed

E-post:	dominik.beckers@taltech.ee

Hariduskäik

2021–2026	Tallinna Tehnikaülikool, PhD
2017–2019	Lundi Ülikool, MSC
2018–2019	Taiwani Riiklik Ülikool, MSC
2014–2017	Utrechti Ülikool, BSC
2016–2017	Islandi Ülikool, BSC
2013–2014	Utrechti Rakenduskõrgkool, BSC
2005–2013	Gymnasium Hammonense, keskharidus

Keelteoskus

Saksa keel	emakeel
Inglise keel	kõrgtase

Teenistuskäik

2021–2026	FinEst Centre for Smart Cities, Tallinna Tehnikaülikool
2021–2026	Urban Innovation Policy Lab, Edinburgh Napier
2017–2024	University Technopolis Group

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