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A Sequential Model of Dynamic Capabilities in Research Groups and Their Impact on Smart City Development

Un modelo secuencial de capacidades dinámicas en los grupos de investigación y su impacto en el desarrollo de ciudades inteligentes

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ABSTRACT

Objective: The aim of this study was to evaluate the systematic influence of the sensing, learning, integrating, and coordinating dimensions of dynamic capabilities on the development of smart cities. Since dynamic capabilities have been examined mainly from the perspective of improving business performance, their relationship with smart cities has received little attention in the scientific literature.
Design/Methodology: A correlational methodology with a quantitative approach was employed. The study proposed hypotheses about the relationships between the sensing, learning, integration, and coordinating capabilities and their impact on the advancement of smart cities. These relationships were assessed in 82 research groups in Manizales, Colombia, through a structural equation model estimated using the Partial Least Squares Structural Equation Modeling (PLS-SEM) technique.
Findings: The results indicate that the dynamic capabilities developed by research groups exert a systematic, positive, and significant influence on smart city development. In addition, the constructs analyzed met the criteria for convergent and discriminant validity, and the model demonstrated acceptable predictive power.
Conclusions: Dynamic capabilities are interdependent and evolve through a cumulative process in which research groups identify opportunities, acquire and manage knowledge, integrate this knowledge into strategic decision-making, and coordinate resources to generate innovations with an impact on urban environments. Therefore, the development and implementation of dynamic capabilities within research groups, aligned with public agendas, are essential to strengthen the shift toward smart cities.
Originality: This study extends the analysis of dynamic capabilities within research organizations. Furthermore, it underlines the role of contextual learning and resource orchestration in fostering responsiveness and innovation across urban ecosystems.

Keywords: dynamic capabilities, smart cities, research groups, Partial Least Squares Structural Equation Modeling (PLS-SEM), knowledge integration.

Highlights

- A sequential model of dynamic capabilities for smart city development is proposed and applied to research groups in a Latin American city.
- Smart city development is positively influenced by an organized sequence of sensing, learning, integrating, and coordinating capabilities developed within research groups.
- Supporting research groups in strengthening their dynamic capabilities is essential to promote urban transformation toward smart cities.
- Collaboration between urban managers and research groups that deploy their dynamic capabilities in a coordinated manner constitutes a fundamental management strategy for consolidating smart cities.

RESUMEN

Objetivo: el objetivo de este estudio fue evaluar la influencia sistemática de las dimensiones de detección, aprendizaje, integración y coordinación de las capacidades dinámicas en el desarrollo de ciudades inteligentes. Debido a que las capacidades dinámicas se han estudiado principalmente desde la perspectiva de la mejora del desempeño empresarial, su relación con las ciudades inteligentes ha recibido escasa atención en la literatura científica.
Diseño/Metodología: se adoptó una metodología correlacional con enfoque cuantitativo. Se plantearon hipótesis de las relaciones entre las capacidades de detección, aprendizaje, integración y coordinación, así como su impacto en la consolidación de ciudades inteligentes. Estas relaciones fueron evaluadas en 82 grupos de investigación de la ciudad de Manizales (Colombia) a través de un modelo de ecuaciones estructurales estimado mediante la técnica modelado de ecuaciones estructurales por mínimos cuadrados parciales (PLS-SEM, por sus siglas en inglés).
Resultados: los hallazgos indican que las capacidades dinámicas desarrolladas por los grupos de investigación ejercen una influencia sistemática, positiva y significativa en el desarrollo de ciudades inteligentes. Asimismo, los constructos analizados cumplieron con los criterios de validez convergente y discriminante, y el modelo mostró un nivel de capacidad predictiva aceptable.
Conclusiones: las capacidades dinámicas son interdependientes y evolucionan mediante un proceso acumulativo donde los grupos de investigación detectan oportunidades, adquieren y gestionan conocimiento, integran dicho conocimiento en la toma de decisiones estratégicas y coordinan recursos para generar innovación con impacto en los entornos urbanos. Por lo tanto, el desarrollo y la aplicación de capacidades dinámicas en los grupos de investigación, alineadas con las agendas públicas, resultan fundamentales para fortalecer la transición hacia ciudades inteligentes.
Originalidad: este estudio extiende el análisis de las capacidades dinámicas en el contexto de las organizaciones de investigación. Además, subraya el papel del aprendizaje contextual y la orquestación de recursos para fomentar la capacidad de respuesta y la innovación en los ecosistemas urbanos.

Palabras clave: capacidades dinámicas, ciudades inteligentes, grupos de investigación, modelado de ecuaciones estructurales por mínimos cuadrados parciales (PLS-SEM), integración del conocimiento.

Highlights

- Se propone un modelo secuencial de capacidades dinámicas para el desarrollo de ciudades inteligentes y se aplica a grupos de investigación de una ciudad latinoamericana.
- El desarrollo de ciudades inteligentes se fortalece a partir de una secuencia articulada de capacidades dinámicas de detección, aprendizaje, integración y coordinación desarrolladas en los grupos de investigación.
- El fortalecimiento de las capacidades dinámicas en los grupos de investigación constituye un elemento esencial para promover procesos de transformación hacia ciudades inteligentes.
- La colaboración entre gestores urbanos y grupos de investigación que desplieguen sus capacidades dinámicas de forma articulada emerge como una estrategia de gestión clave para la consolidación de ciudades inteligentes.

1. INTRODUCTION

Organizational theories concerning strategic management include the concept of dynamic capabilities as a competitive advantage that influences organizational performance in response to technological and market changes (Gheitarani et al., 2023; Wohlleber et al., 2024). Dynamic capabilities provide opportunities for knowledge exploration and exploitation, continuous updating of ordinary or operational capabilities, and constant interaction with the environment (Babelytė-Labanauskė & Nedzinskas, 2017).

Dynamic capabilities are therefore important instruments for not just projecting performance but also measuring the Research, Development, and Innovation (R&D&I) execution of companies and their impact on smart cities (Fredrich et al., 2022). Knowledge as a mediating variable between human capital, learning, creativity, and R&D&I has enabled a dominant evolutionary perspective of urban development (Sikora-Fernandez, 2017). Through this lens, cities are understood as complex systems that are migrating towards smart and sustainable places through the intensive use of digital technologies, favoring the optimization of urban ecosystems (Komninos et al., 2019).

The integration of R&D&I activities is crucial for research organizations and their impact on smart city ecosystems with a clear strategic intent of innovation (Sikora-Fernandez, 2017). They must develop new technologies with business models that successfully lead to the development of prototypes and the transition to real products ready for commercialization (Maranzato et al., 2019).

In this sense, dynamic capabilities provide a relatively novel approach to smart city contexts. Very few studies have linked these capabilities to smart cities (Linde et al., 2021). However, Gupta et al. (2017) established a research agenda on smart cities, including the identification of capabilities that benefit them. According to Guenduez and Mergel (2022), a smart city model should be supported by dynamic capabilities. Additionally, it has been found that the technological transformation of the public sector, which supports smart cities, has resulted from the emergence of this type of capabilities (De Magalhães Santos, 2023).

Hence, this article evaluates how dynamic capabilities of research groups in the city of Manizales, Colombia, influence smart city dimensions. It addresses the scarcity of studies that examine the factors that foster the development of smart cities in Latin America. In this regard, its novel

contribution lies in proposing that dynamic capabilities function as enabling factors for the advancement of smart cities within Latin American urban contexts, strengthening theory and its applications. To date, there is limited scientific literature exploring this relationship, particularly in Colombia and the broader Latin American region.

After this introduction, Section 2 presents the theory of dynamic capabilities and examines the concept of smart cities as the foundations of the study. It also proposes the positive sequential influence of four dynamic capabilities of research groups on smart cities, as well as a conceptual model. Section 3 explains the methodology used to evaluate the measurement model and the structural model. Sections 4 and 5 show and discuss the results according to the theoretical approaches, identifying the practical implications and suggesting future research. Finally, Section 6 presents the conclusions of the study.

2. THEORETICAL FRAMEWORK

Dynamic Capabilities

A firm's dynamic capabilities can be defined as its ability to integrate, develop, and reconfigure both internal and external competencies in response to rapidly changing environments (Teece et al., 1997). This refers to the organization's proactive methods to find different and innovative ways to achieve competitive advantage (Helfat et al., 2007). Therefore, the above calls for differentiation between ordinary and dynamic capabilities (Teece, 2023).

A company's ordinary capabilities reflect its current set of operating procedures that it uses to sell its products to the same customers at the same scale (Winter, 2003). This relates to how an organization "makes a living" in the short term and solves problems (Drnevich & Kriauciunas, 2011; Helfat & Winter, 2011; Karna et al., 2016). In contrast, dynamic capabilities enable organizational change through the detection and exploitation of new opportunities or changes in the environment, leading to the reconfiguration of ordinary capabilities by creating, expanding, or modifying their resource base (Faccin et al., 2019).

The interest in dynamic capabilities arises from the intention to change the status quo in the organization through links between strategy, management, entrepreneurship, and leadership. An example of this is when the leaders of an organization propose changes and, as a result, the workforce supports such changes on a regular basis (Kurtmollaiev, 2020). Dynamic capabilities are classified according to four processes: sensing, learning, integrating, and coordinating (Ester et al., 2010; Hernández-Linares et al., 2021; Matarazzo et al., 2021; Pavlou & El Sawy, 2011; Schilke et al., 2018; Teece, 2023).

Investigations on smart cities and governance have highlighted the critical role of technological preparedness and integrated governance, showing that their absence creates substantial barriers to innovation in developing contexts (Tan & Taeihagh, 2020). Within this broader debate, Latin American scholarship is beginning to develop its own voice, advancing both conceptual and contextual insights. A bibliometric study of the region's scientific output between 2007 and 2017 revealed that the most frequent topics relate to urban technologies, digital governance, and geospatial data, suggesting a growing recognition of the institutional role in smart urban design (Fernandes et al., 2019).

In Brazil, studies have further shown that unequal access to and effective use of digital technologies across individuals, groups, and regions limits the impact of smart government on citizens. This situation highlights tensions between technical capacity, institutional design, and the social demands embedded in governance policies (Leite da Silva et al., 2022). More recently, contributions exploring urban innovation, sustainable strategies, and institutional challenges have begun to expand this conversation in Latin American contexts, pointing to the emergence of a regional perspective on smart city development (Escobar et al., 2024). Taken together, these studies reinforce the need to articulate a Latin American approach that recognizes institutional capacities, digital inequality, and socio-economic conditions as central to ensuring that smart governance strategies effectively contribute to building inclusive and sustainable smart cities.

Sensing Capability

Sensing allows firms to identify trends, market information, and knowledge that have the potential to influence its competitive position (Kump et al., 2019; Makkonen et al., 2014; Teece, 2007, 2014). As a result, sensing detects opportunities or threats based on conjectures or hypotheses relating to economic trends, best practices, competitor activities, customer needs, supplier interactions, government regulations, socio-political currents, Research and Development (R&D) activities, technological advances, among others (Kump et al., 2019; Teece, 2007). The lack of sensing can limit the absorption of new knowledge and information required in learning new capabilities (Bingham et al., 2015; García Pineda et al., 2023; Hodgkinson & Healey, 2011; Kale & Singh, 2007).

Learning Capability

Zollo and Winter (2002) argue that dynamic capabilities are fundamentally the outcome of organizational learning and the development of established forms of collective activity, through which firms systematically generate and adapt their operational routines to enhance strategic success (Cyfert et al., 2021). Organizational knowledge, developed by learning capabilities, is disseminated in novel ways of doing things, evolving organizational routines or new logics in the functioning of an organization that are difficult to replicate (Hermawati, 2020; Teece, 2009).

Previous studies indicate that routines are learned through trial and error and by selecting and retaining past behaviors (Gavetti & Levinthal, 2000). This view is related to the idea that organizational routines are stored as procedural memory (Cohen & Bacdayan, 1994) and to the image of routine responses as quasi-automatic. Moreover, it is consistent with the traditional view of organizational learning as a skill developed on the basis of repeated execution of similar tasks (Argote & Miron-Spektor, 2011; Teece, 2016).

Integrating Capability

Through integrating capability organizations can capture the value of consolidated actions during learning, with the purpose of developing and exploiting business opportunities and evading threats that match the organizations' environment considering their strengths and weaknesses (Karimi-Alaghehband & Rivard, 2020; Kump et al., 2019; Teece, 2014).

Integrating involves bringing together information and knowledge external and internal to the organization, and it is closely related to strategic decision-making (Kump et al., 2019). This involves improving, combining, and protecting tangible and intangible assets, as well as reorganizing and

recombining them to realize the opportunities detected (Karimi-Alaghehband & Rivard, 2020; Yeow et al., 2018). Consequently, this capability is associated with the development of new products, processes, services, and business models by creating organizational frameworks and new procedures (Froehlich et al., 2017; Teece, 2009).

Coordinating Capability

Coordinating is the ability to enhance, combine, protect, and, when necessary, recombine and reconfigure tangible and intangible assets and organizational structures as the organization grows and markets and technologies change, preventing path dependency and inertia (Chien & Tsai, 2012; Liu & Hsu, 2011; Sachitra & Chong, 2018). Therefore, coordinating refers to the implementation of strategic decisions on evolving business models, products, or process innovations through the implementation of new structures and routines (Teece, 2023). When an organization lacks coordination, redundant resources and skills may reduce its operational flexibility, which is undesirable from the perspective of environmental dynamics (Cyfert et al., 2021; Kump et al., 2019; Maranzato & Salerno, 2018).

Dynamic Capabilities in Knowledge-Based Organizations

Although the literature on dynamic capabilities in research organizations is limited, existing studies emphasize their importance despite perceptions of rigidity to change and reliance on infrastructure for R&D&I outcomes (Babelytė-Labanauskė & Nedzinskas, 2017). In scholarly debates, such organizations are often described as knowledge-based entities (Güldenberg & Leitner, 2008), where the transition from basic to applied research, innovation, and research management has become increasingly complex and bureaucratic, requiring shared leadership (Kulakowski & Chronister, 2006). This complexity is reflected in frameworks such as the triple helix, which highlights collaboration among academia, industry, and government for knowledge-driven development (Galvao et al., 2019; Leydesdorff, 2012). Thus, inter-institutional cooperation becomes central to R&D&I agendas (Benner & Sandstrom, 2000) and to the orientation of research towards societal and market needs (Etzkowitz & Leydesdorff, 2000; Philpott et al., 2011).

In this context, research organizations that effectively exploit dynamic capabilities demonstrate improved performance in turbulent environments by integrating diverse stakeholders and adapting to regional demands (Babelytė-Labanauskė & Nedzinskas, 2017). Unlike traditional firms that measure success mainly in financial terms, their performance depends on leadership and governance capacity to reconfigure resources and achieve organizational flexibility. This enables them to balance academic outputs with social and market demands through the commercialization of R&D&I results, while developing core dynamic capabilities such as sensing, learning, integration, and coordination (Babelytė-Labanauskė & Nedzinskas, 2017).

Smart Cities

The smart city concept is a consequence of the evolution of urban centers. This evolution has progressed from cities as scientific hubs, through eco-cities focused on renewable energy and environmental protection, and digital cities characterized by intensive use of Information and Communication Technology (ICT), to smart cities based on knowledge-driven economies. Today, the most advanced form is a city that uses ICT to enhance the interactivity and efficiency of urban infrastructure and its

components, as well as to increase residents' awareness (Wdowiarz-Bilska, 2012). A smart city uses ICT to optimize the effectiveness of necessary and useful city processes, usually by linking various components and stakeholders in a smart system that collaborates without fail (Su et al., 2011).

Smart city definitions comprise four common elements (Seisdedos, 2016). The first aspect is a holistic or global vision; a smart city is present in all areas of its jurisdiction and is reflected in its management, which unifies and coordinates urban zones and actors transversally. The second component is a means to accomplish certain objectives; the concept of intelligence associated with the city is not an end in itself but a means to achieve priority objectives for cities. These include improving public services and the quality of life of citizens, making the local productive sector more competitive and innovative, and generating an environmentally sustainable space for coexistence. The third ingredient is technology as a disruptive factor; the key to achieving these objectives is the use of technology that collects large amounts of data and processes and shares them in real time in the form of relevant information to generate added value. The fourth element is a new model of relationships based on economic changes (moving to a collaborative economy), social changes (new forms of resident participation), and municipal changes (facilitating the adoption of more agile and transparent urban policies).

The smart city framework is structured around six key dimensions: economy, people, environment, governance, mobility, and living. Smart economy emphasizes productivity, flexible labor markets, and innovation-driven industries, particularly through ICT applications in manufacturing and construction, while also addressing challenges in internationalization, infrastructure, and teleworking (Giffinger & Gudrun, 2010). Smart people represent the distinctive factor of digital cities, defined by education, skills, and civic collaboration, as well as their ability to connect globally (Azkuna, 2012; Madkour et al., 2015). Smart environment involves the adoption of advanced technologies, such as remote sensing and geographic information systems, to mitigate climate change, pollution, and resource management issues (Bokolo et al., 2018). Smart governance entails citizen participation, e-government, and e-democracy, supported by innovative technologies that strengthen transparency and service delivery (Giffinger et al., 2007; Marciniak & Owoc, 2013). Smart mobility focuses on sustainable, efficient, and safe transport systems through real-time information sharing, renewable energy use, and improved infrastructure (Azkuna, 2012; Giffinger et al., 2007) Finally, smart living covers quality-of-life factors such as education, health, housing, security, and tourism, where technologies like massive open online courses, e-medical records, surveillance systems, and digital platforms improve accessibility, safety, and cultural development (Azkuna, 2012; Giffinger et al., 2007).

Importantly, smart cities depend directly on the innovation management strategies implemented by public administrations (Beckers & Mora, 2025). Such management guides R&D initiatives that sustain the technological innovations required for integrated urban solutions (Cambra-Fierro et al., 2024) and involves knowledge absorption from diverse urban actors to foster collaborative innovation (Adjei-Bamfo et al., 2019). In this role, innovation management in the public sector acts as a strategic leader and orchestrator of human capital and resources essential for initiating and advancing smart city projects (Ferraris et al., 2020). However, Ferraris et al. (2020) note the need for public managers to move beyond a preference for stability and embrace risk-taking and proactivity to strengthen innovation processes for smart cities.

From this perspective, smart cities should be approached as open innovation platforms (Mainka et al., 2016), where public innovation management relies on open government principles and the active

integration of urban knowledge (Ferraris et al., 2020). This approach enables the use of consolidated methodologies and theories (such as open innovation, sensemaking, technology roadmapping, and innovation intermediation) to provide coherence, flexibility, and legitimacy to smart city projects (Beckers & Mora, 2025). As a result, initiatives are not fragmented into isolated technological solutions but evolve into broader socio-technical processes with economic, social, and environmental impacts on smart cities (Ferraris et al., 2020).

Research Hypothesis

Recent scholarship increasingly demonstrates that dynamic capabilities are central to the development of smart cities. Evidence shows that municipalities capable of sensing opportunities, prioritizing initiatives, and reconfiguring resources are more likely to generate public value through projects such as open data and digital services (Chong et al., 2018). Research on dynamic capabilities further indicates that systematically exploring opportunities, integrating resources across organizations, and empowering teams accelerates urban transformation by orchestrating innovation across complex ecosystems (Guenduez & Mergel, 2022). Comparative studies also reveal that cities with more advanced dynamic capabilities are better positioned to sustain innovation outcomes over time, particularly when implementing smart policies and projects at scale (Chen et al., 2024; Guo & Zhong, 2022). In addition, recent contributions confirm that these capabilities can be deliberately cultivated and measured within local governments. In this way, governments enhance their adaptive capacity to confront challenges such as climate change and mobility, while reinforcing institutional resilience as a foundation for smart city development (Kattel, 2022; Kattel et al., 2025).

Building on this body of research, the present study argues that the systematic interplay of sensing, learning, integrating, and coordinating capabilities represents a fundamental mechanism through which cities advance towards smart models. This perspective provides the rationale for the research hypotheses developed below, which address the systematic influence of the dimensions of dynamic capabilities on the evolution of smart cities.

Influence of Sensing on Learning

Teece (2007) explains that an adequate business model is a micro-foundation of learning. In the context of research groups, once a new opportunity is detected, groups must create projects and products (business models) to define their development, publications, commercialization, investments strategies, and priorities. These definitions require calculated assumptions about the behavior of competitors and market segments based on information and intelligence about the environment, which is gathered through sensing capabilities. As Liu and Yang (2020) put it, sensing entails gathering and analyzing information to better understand the needs and demands of customers as well as predict the reaction of competitors. Therefore, the goal is to exploit combinations of resources and capabilities based on detected opportunities (Matysiak et al., 2018). Torres et al. (2018) show that firms can benefit from more opportunities by detecting a wide variety of competitive actions. Based on the above, it can be assumed that sensing facilitates learning, and the following hypothesis is formulated:

Hypothesis 1 (H1): Sensing capability positively influences learning capability in research groups.

Influence of Learning on Integrating

Learning encompasses a wide range of activities, including not only formal communications—such as planning sessions, regular meetings, training programs, and employee education—but also internal and external social interactions to share information (Iansiti & Lakhani, 2020; Lee & Klassen, 2008; Vachon & Klassen 2006). Research group staff can use knowledge transfer to seek out and share sustainable concerns, thereby following social interaction routines to support the free exchange of knowledge (Alvarez et al., 2010). Hart and Sharma (2004) describe this social interaction process as a center-to-periphery network approach. Lee and Klassen (2008) and Alvarez et al. (2010) show that integration-based knowledge transfer often generates novel perspectives on sustainability and thus enables firms to find creative ways to cooperate with external stakeholders for mutual benefits. Therefore, the following research hypothesis is formulated:

Hypothesis 2 (H2): Learning capability positively influences integrating capability in research groups.

Influence of Integrating in Coordinating

Integration implies the firm's ability to assess the value of existing resources and transform them to shape more efficient capabilities (Iansiti & Clark, 1994). In addition, it has to do with understanding how new resources can be used to create stronger competitive advantages. Consequently, derived from this dynamic capability, an organization knows how to implement an innovative business model or strategy (Sanchez & Heene, 1997). Through the initiatives of research groups, new knowledge that improves the conditions of cities is generated. This implies that research groups understand how to apply such knowledge and have therefore developed a strategy to facilitate city innovation (Iansiti & Clark, 1994). In cities, research groups assist in integrating knowledge that guides and supports the coordination of resources to implement a smart city ecosystem (Helfat & Raubitschek, 2000). Accordingly, the following hypothesis is formulated:

Hypothesis 3 (H3): Integrating capability positively influences coordinating capability in research groups.

Influence of Coordinating on Smart Cities

Coordination involves orchestrating tasks and activities for the deployment of new capabilities (Teece, 2023). Thus, it helps multifunctional teams made up of members of different organizations or business units to collaboratively develop new products and processes (Helfat et al., 2007). Coordinating capability aligns innovation and research efforts with organization objectives (Kelly, 2009) and implies that firms use acquired innovations to develop enhanced products, services, and processes for commercialization or deployment (Protogerou et al., 2012). A study by Okhuysen and Bechky (2009) revealed that coordination mechanisms facilitate the transfer of innovations from the R&D stage to the implementation stage (Chang et al. 2012).

Hence, this dynamic capability developed by research groups influences the implementation of smart city dimensions. Notably, these initiatives are based on innovations such as reconfiguring the operational capacity of the city through information technology systems and infrastructure to support and improve traditional city services in the most efficient manner (Chong et al., 2018). Consequently, coordinating, as a research group capability, supports the creation, adaptation, and renewal of the processes and services that take place in a city. For this reason, a city can become a smart city, and the following hypothesis is formulated:

Hypothesis 4 (H4): Coordinating capability positively influences the smart city construct in research groups.

The theoretical model tested through a system of structural equations is presented in Figure 1. It shows a causal chain of relationships between dynamic competencies and the smart city construct. This sequential model indicates that dynamic capabilities operate as an interconnected and cumulative mechanism through which research groups contribute to smart city development. First, sensing capability enables the identification, interpretation, and anticipation of environmental opportunities, thereby facilitating organizational learning through the acquisition and analysis of strategic information (Liu & Yang, 2020; Matysiak et al., 2018). In turn, learning capability promotes the integration of knowledge by supporting social interaction, knowledge transfer, and collaboration among internal and external stakeholders, which fosters innovative perspectives and collective problem-solving processes (Iansiti & Lakhani, 2020; Lee & Klassen, 2008). Subsequently, integrating capability allows organizations to transform and recombine resources into stronger capabilities that support innovation strategies and the implementation of urban solutions (Iansiti & Clark, 1994; Sanchez & Heene, 1997). Finally, coordinating capability orchestrates activities, resources, and innovation efforts to facilitate the deployment of smart technologies, processes, and services within cities, ultimately affecting in a positive manner the smart city deployment (Chong et al., 2018; Helfat et al., 2007). Collectively, this sequential relationship explains how dynamic capabilities evolve from opportunity recognition to coordinated urban transformation, providing a coherent theoretical foundation for the proposed conceptual model.

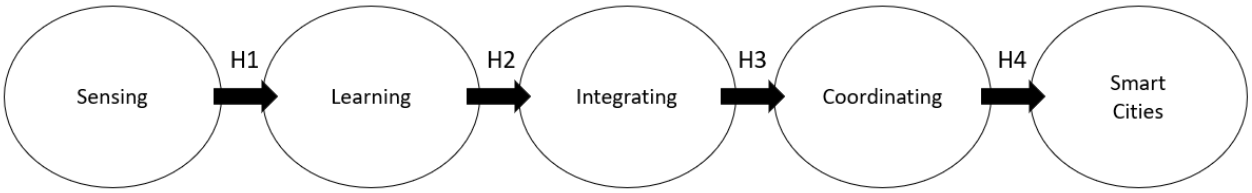


Figure 1. Conceptual model
Figura 1. Modelo conceptual
Source: own elaboration.

3. METHODOLOGY

Context of the Study

This study was conducted with research groups in Manizales, Colombia, because they have contributed to this city's capacity to improve its services through their research, development, and innovation results. They have also leveraged information technologies to offer residents novel services and products, facilitating the consolidation of the smart city dimensions mentioned above and generating many of the smart city products offered in Manizales. In addition, since they are constantly creating new knowledge, they have developed dynamic capabilities, transcending from being eminently academic to having a direct impact on market conditions and citizens' welfare (Philpott et al., 2011).

In particular, Manizales was selected as the empirical setting because it is an intermediate city with demonstrated advances in smart city development in Latin America. It has been ranked by the

National Planning Department (DNP) as the most modern city in Colombia, leading in key dimensions such as governance, science and technology, and sustainability (DNP, 2023). Beyond this performance, Manizales represents a knowledge-intensive urban context characterized by the presence of favorably recognized higher education institutions. The city also showcases a dense concentration of research groups classified within the national science and technology system, many of which are top-tier (A1 and A), indicating strong capabilities in research, development, and innovation (Ministerio de Ciencia, Tecnología e Innovación [MinCiencias], n. d.). Its inclusion in the UNESCO Global Network of Learning Cities further reflects an institutional orientation towards knowledge-based development and coordinated governance (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2020). These conditions make Manizales an appropriate setting to examine how dynamic capabilities unfold within research groups and translate into smart city development, consistent with prior research on institutional and technological capacities in intermediate urban contexts (Guenduez & Mergel, 2022; Fernandes et al., 2019; Tan & Taeihagh, 2020).

Sample and Data Collection Procedure

A total of 82 research groups from Manizales participated in this study, out of 182 eligible groups, which represents a response rate of 47%. These groups were selected because they are officially recognized by the Ministry of Science, Technology, and Innovation of Colombia and are affiliated with universities in Manizales. Two surveys were administered. The first survey measured dynamic capabilities using the scale developed by Pavlou and El Sawy (2011). This scale includes six items for sensing, four for learning, six for integration, and five for coordination. The second survey assessed smart city dimensions based on established scales in the literature (Anthopoulos et al., 2016; Giffinger & Gudrun, 2010; Jnr et al., 2017; Kumar & Dahiya, 2017; Mishra et al., 2017; Tahir & Malek, 2016). It includes seven items for smart economy, four for smart people, six for smart governance, eight for smart mobility, ten for smart environment, 11 for smart living, and 13 for smart city adoption. Both instruments used a seven-point Likert scale, where 1 represents the minimum level and 7 the maximum level. The surveys are provided in Appendices A and B.

The survey on dynamic capabilities was administered to research and development directors. In addition, the smart city survey was administered to administrative or general directors of these same groups. This decision reflects differences in expertise. While research and development directors are familiar with the process of developing novel products and services from the perspective of dynamic capabilities, administrative and general directors are more knowledgeable about the application of these capabilities within Manizales. This separation helps reduce potential bias in the analysis of the relationship between dynamic capabilities and smart cities. The surveys were distributed through the SurveyMonkey platform, which enabled monitoring of response progress. Follow-up telephone calls were used to encourage participation. Data collection took place between July and September 2022.

Data Analysis Technique

This study used Partial Least Squares Structural Equation Modeling (PLS-SEM) for data analysis. This technique is appropriate to assess relationships that are new theoretical developments, such as those proposed in this study's hypotheses(Hair et al., 2014). Additionally, PLS-SEM can be used to evaluate complex theoretical models involving multiple variables, as shown in Figure 1 (Hair Jr. et al., 2017). PLS-SEM involves two analysis processes (Hair et al., 2014). The first step evaluates the

measurement model, aiming specifically to determine if the measures employed in the study reach convergent and discriminant validity (Hair Jr. et al., 2017). The second process assesses the structural model, which in turn evaluates the relationships that are indicated in the research hypotheses (Hair et al., 2014).

4. RESULTS

Measurement Model Evaluation

As a first step, the literature on PLS-SEM recommends that the evaluation of the measurement model used should be performed on all the constructs involved in the relationships (Hair et al., 2014). Several constructs were integrated into the measurement model: sensing, learning, integrating, coordinating, smart economy, smart people, smart governance, smart mobility, smart environment, smart living, and smart city adoption. This measurement model achieved convergent validity as shown in Table 1.

Firstly, all construct items obtained standardized loadings, which were mostly greater than 0.6. This is a requirement according to the PLS-SEM literature because it indicates that the convergent validity values of the items used in the surveys theoretically represent each construct (Hair et al., 2014). Secondly, all measurement constructs exceeded the 0.7 threshold required for Cronbach's alpha and composite reliability indicators. Finally, the average variance extracted reached values above 0.5 in each construct, which is usually recommended in the PLS-SEM literature (Hair et al., 2014).

Table 1. Convergent validity results
Tabla 1. Resultados de validez convergente

Construct	Cronbach's Alpha	Composite Reliability	Average Variance Extracted
Sensing	0,85	0,89	0,63
Learning	0,77	0,85	0,59
Integrating	0,92	0,93	0,71
Coordinating	0,84	0,89	0,68
Smart Economy	0,87	0,91	0,67
Smart People	0,81	0,89	0,73
Smart Governance	0,77	0,87	0,69
Smart Mobility	0,83	0,88	0,66
Smart Environmental	0,82	0,88	0,67
Smart Living	0,90	0,92	0,63
Smart City Adoption	0,91	0,93	0,66

Source: Authors' own work based on Ringle et al. (2022).

In addition, the measurement model achieved discriminant validity, as evaluated through the Heterotrait-Monotrait Ratio of Correlations (HTMT). The literature on PLS-SEM advices that this indicator, which is established between pairs of variables, be less than 0.9 (Henseler et al., 2015). Table 2 shows that it did not exceed that value in this study, indicating that the measurement

constructs are different. The results of the convergent and discriminant validity analyses show that the measurement model adequately reflects the underlying theoretical model from which the questionnaires were derived for each construct.

Table 2. Discriminant validity results (HTMT)

Tabla 2. Resultados de la validez discriminante (HTMT)

Construct	1	2	3	4	5	6	7	8	8	10
Sensing										
Learning	0,71									
Integrating	0,82	0,85								
Coordinating	0,87	0,76	0,67							
Smart Economy	0,21	0,44	0,27	0,28						
Smart People	0,23	0,45	0,56	0,37	0,39					
Smart Governance	0,43	0,34	0,33	0,36	0,52	0,67				
Smart Mobility	0,33	0,35	0,22	0,21	0,69	0,81	0,58			
Smart Environmental	0,41	0,45	0,56	0,67	0,72	0,77	0,89	0,79		
Smart Living	0,24	0,27	0,28	0,31	0,73	0,67	0,59	0,73	0,65	
Smart City Adoption	0,33	0,40	0,52	0,35	0,78	0,70	0,83	0,81	0,76	0,88

Source: Authors' own work based on Ringle et al. (2022).

In this study, *smart cities* was treated as a reflective–formative construct of a second order because it comprises seven variables: smart economy, smart people, smart governance, smart mobility, smart environment, smart living, and smart city adoption. To evaluate this model, the two-stage process recommended in the PLS-SEM literature (Hair et al., 2014) was applied. Based on this, the Variance Inflation Factor (VIF) and weights of each construct were calculated. The VIF must be less than 5 and weights must be significant (Hair Jr. et al., 2019). If both conditions occur (Hair et al., 2014), the reflective–formative construct is appropriate to measure the main variable. As shown in Table 3, all seven sub-constructs are relevant to measuring the latter variable.

Table 3. Evaluation of the reflective-formative construct

Tabla 3. Evaluación del constructo reflexivo-formativo

Second-order construct	First-order construct	VIF	First-order construct weight on second-order construct
Smart Cities	Smart Economy	0,32	0,133*
	Smart People	0,43	0,106*
	Smart Governance	0,35	0,107*
	Smart Mobility	0,37	0,141*
	Smart Environmental	0,37	0,170*
	Smart Living	0,39	0,243*
	Smart City Adoption	0,19	0,100*

Note: *Weights were significant at 99 %.

Authors' own work based on Ringle et al. (2022).

Structural Model Assessment

Drawing on the literature about PLS-SEM (Hair et al., 2014), the structural model underwent a hypotheses evaluation. It was demonstrated that sensing positively influences learning (β=0.64; T-value=3.45), which in turn positively influences integration (β=0.56; T-value=4.52). In addition, this dynamic

capability positively influences coordination (β=0.70; T-value=2.67), which then positively impacts the smart city dimension (β=0.41; T-value=4.77). All these relationships were significant, supporting the four research hypotheses. Table 4 summarizes these results.

Finally, the predictive power of the identified relationships was evaluated within the sample through the R2 indicator. When exceeding the threshold of 0.1 in the dependent variables, this value indicates that the results have significant predictive power (Hair et al., 2014). This occurred in the four dependent variables established in the model (learning, integrating, coordinating, and smart cities).

Table 4. Hypothesis testing results

Tabla 4. Resultados de la comprobación de hipótesis

Direct effect			
Relationship	**Path Coefficient**	**T-Value**	**Result**
Sensing → Learning	0,64	3,45	H1 supported
Learning → Integrating	0,56	4,52	H2 supported
Integrating → Coordinating	0,70	2,67	H3 supported
Coordinating → Smart cities	0,41	4,67	H4 supported
Learning R2: 0,41 Integrating R2: 0,31 Coordinating R2: 0,49 Smart cities R2: 0,17			

* Significance of 99 % for t-values exceeding the threshold of 2.5.

Source: Authors' own work based on Ringle et al. (2022).

5. DISCUSSION

This study introduces an original analytical perspective by empirically examining the sequential interaction of dynamic capabilities within the context of urban processes associated with smart cities. While prior theoretical frameworks have outlined the relevance of such capabilities, empirical evidence on their interconnected progression in research-driven environments remains scarce (Matarazzo et al., 2021; Schilke et al., 2018).

Confirmation of H1 demonstrates that research groups actively monitor their external environments to identify emerging needs and opportunities. This sensing strengthens their learning capabilities by enabling the assimilation of novel routines, behaviors, and knowledge structures (Kump et al., 2019; Teece, 2007, 2014). Thus, opportunity recognition serves as a foundation for developing learning, a necessary characteristic of dynamic capabilities (Hermawati, 2020; Liu & Yang, 2020; Matysiak et al., 2018; Teece, 2016).

Support for H2 suggests that learning capabilities have a positive influence on integration capabilities. This result reinforces existing arguments regarding the dynamic nature of organizational knowledge bases, particularly in research institutions (Cyfert et al., 2021). As research groups accumulate knowledge, they engage in practices that encourage collective sense-making and knowledge-sharing to support decision-making processes (Kelly, 2009; Kump et al., 2019). These findings are consistent with the view that integrating dispersed knowledge is crucial for leveraging identified opportunities (Karimi-Alaghehband & Rivard, 2020; Teece, 2007; Yeow et al., 2018).

Building upon this logic, H3 was also supported, substantiating the idea that integrative capabilities enable more effective coordination among research teams. By aligning and mobilizing internal resources, research groups are better positioned to implement innovations or adjust operational procedures (Helfat & Raubitschek, 2000; Teece, 2023). Coordinated action depends not only on access to resources but on a shared understanding of how knowledge translates into strategic response. Furthermore, the results supporting H4 demonstrate that coordination capabilities—encompassing the structuring and deployment of new competencies—are vital for enacting strategic decisions and enabling innovation pathways in urban development (Chien & Tsai, 2012; Chong et al., 2018; Liu & Hsu, 2011; Sachitra & Chong, 2018).

These findings are consistent with and extend previous research that highlights the central role of dynamic capabilities in the development of smart cities. The dynamic capabilities framework, understood through sensing, learning, integrating and coordinating, shows that cities capable of recognizing opportunities, prioritizing initiatives, and reorganizing resources are more effective in creating public value through projects such as open data systems and digital services (Chong et al., 2018). In a similar direction, studies on dynamic capabilities reveal that the abilities to explore opportunities, connect resources across organizations, and empower teams contribute to accelerating urban transformations by orchestrating innovation in diverse ecosystems (Guenduez & Mergel, 2022).

Beyond these specific mechanisms, research has shown more broadly that cities which cultivate dynamic capabilities are better positioned to sustain innovation, adapt to changing environments, and align diverse stakeholders around coherent strategies. Comparative evidence demonstrates that the systematic development of dynamic capabilities leads cities to achieving more consistent and long-lasting results in implementing smart initiatives, underlining the importance of coordination and institutional flexibility (Chen et al., 2024; Guo & Zhong, 2022). Furthermore, recent studies confirm that these capabilities can be deliberately built and measured in local governments, providing administrations with the resilience required to respond effectively to pressing urban challenges such as climate change, mobility, and social inclusion (Kattel, 2022; Kattel et al., 2025).

Altogether, these perspectives, combined with the evidence presented in this study, suggest that the evolution of smart cities cannot be reduced to the implementation of new technologies alone. What truly drives their formation is the systematic interaction of sensing, learning, integrating and coordinating capabilities. When these capabilities operate together, they allow cities to transform resources, align diverse stakeholders, and implement coherent solutions that balance technological innovation with social, economic, and environmental objectives. This study contributes to this body of knowledge by showing that the convergence of dynamic capabilities provides the institutional and organizational basis required for the sustainable advancement of smart cities.

In practical terms, the findings of this study offer significant implications for urban managers, academic leaders, and public policy makers. The identification of a causal relationship between the dynamic capabilities of research groups and the consolidation of smart city dimensions indicates that the success of urban innovation relies on the effective management of knowledge, resources, and collaborative networks. Within the logic of the triple and quadruple helix, research groups are not only producers of knowledge but also mediators that connect universities, industry, governments, and civil society, thereby facilitating the circulation of ideas and the joint development of solutions. Their ability to anticipate technological trends, combine interdisciplinary expertise, and adapt institutional arrangements is essential for aligning academic research with the demands of society and urban

contexts. When governments and institutions provide sustained support through adequate funding, regulatory frameworks, and inclusive policies, these capabilities are translated into concrete applications in domains such as mobility, digital governance, environmental sustainability, and citizen participation. In this process, urban managers and policy makers acquire a strategic role as coordinators who transform fragmented efforts into integrated governance models capable of addressing Latin America's socio-economic inequalities, institutional constraints, and cultural diversity. As a result, they foster the development of smart cities that are innovative, inclusive, and resilient.

The study was limited to research groups located in Manizales, Colombia, which may constrain the generalizability of the findings. Additionally, the cross-sectional design prevents causal conclusions. Research group leaders' responses may also introduce subjective bias. Nevertheless, the use of PLS-SEM ensured the robustness of the findings by validating both convergent and discriminant measurement properties.

Future studies could explore how dynamic capabilities shape research productivity and innovation outcomes within academic teams. Understanding how scholarly outputs contribute to specific smart city projects remains relevant. Moreover, it is critical to analyze the role of additional stakeholders—such as government agencies, commercial sectors, non-governmental organizations, and civil society—and their interactions with research entities in advancing smart urban ecosystems.

6. CONCLUSIONS

This study advances the understanding of dynamic capabilities by evidencing their sequential structure and collective impact when oriented towards urban innovation processes. The empirical model demonstrates that sensing capabilities initiate a chain reaction, enhancing learning, which then supports integration, ultimately leading to effective coordination. This sequence significantly influences the smart city dimension, challenging the conventional view of capabilities as simultaneous and isolated functions.

By emphasizing the interdependence of these four capabilities, the findings offer a process-based explanation for how research groups contribute strategically to urban development. Such a progression suggests that dynamic capabilities evolve through accumulative refinement rather than separated deployment, especially in knowledge-intensive environments.

The results imply that leaders within research organizations must synchronize their strategies for sensing, learning, integrating, and coordinating. The empirical framework proposed in this study allows for the design of practical pathways to strengthen institutional capacities aligned with urban impact. It also underscores the role of contextual learning and resource orchestration in fostering responsiveness and innovation within city ecosystems.

Strategic information management, facilitated by organizational learning, equips research teams to act decisively and creatively in response to urban challenges. Harmonizing these capabilities with public policy and institutional priorities can bridge the gap between academic expertise and urban transformation agendas. Accordingly, systematically strengthening dynamic capabilities is essential for transforming research entities into catalysts for sustainable and intelligent city change.

CONFLICTS OF INTEREST

The authors declare no financial, professional, or personal conflicts of interest that could have inappropriately influenced the results or interpretations presented in this study.

AUTHOR CONTRIBUTIONS

All authors contributed significantly to the development of this article, including its design, conceptual framework, methodology, data analysis, and manuscript writing and revision the final version of the manuscript.

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Annexes

Annex A. Questionnaire items on dynamic capabilities
Anexo A. Preguntas del cuestionario sobre capacidades dinámicas

Dynamic capability	Items
Sensing capability	SC1 - Frequency of monitoring research projects.
	SC2 - Level of use of technological and systematic tools in the group's activities.
	SC3 - Frequency of information search activities.
	SC4 - Frequency of technological surveillance and knowledge updating within the group's core of expertise.
	SC5 - Frequency of monitoring changes in the social and technological environment.
	SC6 - Weekly intensity of time devoted to idea generation and new design of capabilities.
Integration capability	IC1 - Level of participation of group members in contributing individual knowledge to projects.
	IC 2 - Level of understanding of tasks and responsibilities among group members.
	IC 3 - Level of identification of skills within the group.
	IC 4 - Capability to develop unique and valuable talent and incorporate it into the group's knowledge base.
	IC 5 - Level of interaction among group members.
	IC 6 - Level of connectivity among group members.
Coordinating capability	CC1 - Alignment between the group's capabilities and the general and specialized competencies of its members.
	CC2 - Level of productivity in response to changes in the sociotechnical and cultural environment.
	CC3 - Capability to monitor knowledge gaps.
	CC4 - Degree of identification of technological markets within the sociocultural and technical environment.
	CC5 - Level of monitoring of technological trajectories in products, processes, and business models.
Learning capability	LC1 - Ability to compare knowledge streams, combine capabilities, and deploy competencies.
	LC2 - Number of effective routines for identifying, evaluating, and incorporating new information and knowledge into core strategic competencies.
	LC3 - Frequency of transforming existing knowledge and information into new knowledge.
	LC4 - Effectiveness of transforming existing knowledge and information into new products and processes.

Annex B. Questionnaire items on Smart City

Anexo B. Preguntas del cuestionario sobre la Ciudad Inteligente

Smart City Dimensions	Items
Smart Economy	SE1 - Deployment of ICT in businesses.
	SE2 - Strategic planning for the city's economic development.
	SE3 - Talent attraction, retention, and creativity promotion.
	SE4 - Support for entrepreneurship.
	SE5 - Development of business networks and collaborations.
	SE6 - International promotion strategies for the city.
	SE7 - Provision of tax payment systems.
Smart People	SP1 - Presence of higher education institutions in the city.
	SP2 - ICT integration and digital development in classrooms.
	SP3 - Collaboration between firms and knowledge institutions.
	SP4 - Presence of research, development, and innovation plans.
Smart Governance	SG1 - Promotion of ICT, innovation, and online public services.
	SG2 - Availability of official government websites.
	SG3 - Presence of strategic plans for e-government development.
	SG4 - Use of internet-connected computers by administrative staff.
	SG5 - Transparency and citizen participation.
	SG6 - Implementation of e-democracy and electronic voting systems.
	SG7 - Availability of birth and death registration.
Smart Mobility	SM1 - International accessibility.
	SM2 - Availability of innovative and safe transport systems.
	SM3 – Effective traffic and parking management systems.
	SM4 - Availability of bicycle lanes and unobstructed pedestrian pathways.
	SM5 - Availability of ICT infrastructure through internet service providers.
	SM6 - Internet use and broadband coverage.
	SM7 - Mobile phone and mobile internet use.
	SM8 - Availability of public internet access and Wi-Fi hotspots.
Smart Environment	SEN1 - Attractiveness of natural conditions.
	SEN2 - Support for pollution reduction.
	SEN3 - Environmental protection measures.
	SEN4 - Availability of sewerage and wastewater treatment systems.
	SEN5 - Adoption of green practices and solid waste recycling.
	SEN6 - Promotion of sustainable resource management.
	SEN7 - Use of ICT to improve public safety.
	SEN8 - Implementation of initiatives for the digitization of cultural heritage assets.
	SEN9 – availability of disaster prediction and early warning systems.
	SEN10 - Availability of fire stations and disaster alarm systems.

Smart City Dimensions	Items
Smart Living	SL1 - Promotion of ICT use in households.
	SL2 - Implementation of e-health policies.
	SL3 - Availability of online medical services.
	SL4 - Availability of emergency response services (e.g., ambulances, emergency units, healthcare facilities).
	SL5 - Availability of remote home monitoring or alarm systems for patients.
	SL6 - Development of digital inclusion programs for vulnerable populations.
	SL7 - Guarantee of personal safety and better housing quality.
	SL8 - Promotion of tourism attractiveness and social cohesion.
	SL9 - Provision of uninterrupted electricity supply.
	SL10 - Provision of uninterrupted water supply.
	SL11 - Availability of metering and online payment of public utilities.
Smart City Adoption	SCR1 - My city actively promotes efficient governance and management for sustainable development and improved livability.
	SCR2 - My city highly values creativity and welcomes new ideas.
	SCR3 - My city offers diverse economic opportunities.
	SCR4 - My city prioritizes pedestrian mobility over vehicle use.
	SCR5 - My city promotes walkability and cycling.
	SCR6 - My city preserves and protects its ecological systems.
	SCR7 - My city efficiently and effectively manages its natural resources.
	SCR8 - My city promotes water conservation and minimizes unnecessary water consumption.
	SCR9 - My city has and continually upgrades its resilience to climate change impacts.
	SCR10 - My city fosters a low carbon environment through energy efficiency and renewable energy.
	SCR11 - My city provides accessible and open public spaces.
	SCR12 - My city provides public services and amenities.
	SCR13 - My city implements e-governance systems for the benefit of its residents.