Decoding the Landscape of Smart City Platforms: A Taxonomy Approach

Research Paper

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Abstract. The notion of Smart Cities (SCs) has gained significant attention in recent years as cities become increasingly connected, integrated, and technologically advanced. Smart City Platforms (SCPs) are an important element of this movement representing the backbone for collecting, processing and analyzing urban data streams from peripheral devices and systems in a city. This study seeks to identify the key dimensions and characteristics of SCPs. Based on existing literature, we craft a taxonomy following Nickerson et al.'s (2013) guidelines. The resulting SCP taxonomy contributes to the literature on SCs by offering a set of characterizations of SCPs that provide a framework to analyze SCPs and identify types of SCPs.

Keywords: Smart City, Smart City Platform, Taxonomy.

1 Introduction

City management faces issues of traffic jams, environmental pollution, energy consumption, and social cohesion. Issues which the increasing urbanization will intensify (Bibri, 2020; Kaluarachchi, 2022). The smart city (SC) phenomenon seeks to address these problems (Batty, 2013). SCs are socio-technical systems that utilize information and communication technology (ICT) to collect, store, and process vast amounts of data to stimulate human- and social capital while improving the quality of life (QOL) for citizens (Bibri, 2019; Fahmideh & Zowghi, 2020; Hollands, 2008). Thus, based on the notion of the Internet of Things (IoT), SCs comprise several interconnected ICTs, such as physical infrastructure, communication systems, and sensors which create smart city platforms (SCPs) (Albino et al., 2015; Bibri, 2018). The European Innovation Partnership on Smart Cities and Communities define SCPs as the backbone for the integration and management of various technological solutions, data collection and analysis, and the delivery of services to citizens (EIP-SCC, 2016).
SCPs enable different components of SCs to communicate with each other and share data, thereby enabling cities to operate more efficiently and effectively (Bouskela et al., 2016). The utilization of ICTs for conducting assignments within a social system has been found to result in a significant transformation in the socio-technical system of a

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city (Fahmideh & Zowghi, 2020; Lyytinen & Newman, 2008). As such, SCPs constitute high complexity and challenges for cities, i.e., through their deep embedding in the cities' infrastructure, heterogeneous systems and technologies must coexist and interact with several stakeholders (Yigitcanlar et al., 2018). Thus, SCPs are vital for bridging social and technical aspects of SCs and facilitating interactions among city stakeholders (Ballon et al., 2011; Patti & Acquaviva, 2016; Santana et al., 2018).
Hitherto, several studies acknowledge different requirements for SCPs. However, they root these requirements in different SCP types (Anttiroiko et al., 2014; Javed et al., 2020; Santana et al., 2018). Thus, missing a typification of SCPs can cause issues in mapping requirements to the right SCP type (Mijuskovic et al., 2021; Santana et al., 2018). Further, the absence of a typification – a theory of analysis clarifying what something is (Gregor, 2006) - limits our ability to compare findings from previous research and to make theoretical generalizations based on respective comparisons. That is, if we cannot identify two SCPs as the same type, how can we deduce insightful propositions about these SCPs? Therefore, we suggest that a profound classification is necessary for IS researchers to aggregate existing knowledge about SCPs; the initial point for platform design, the explanation of interdependencies, and the assessment of risks, patterns, and characteristics (Schermuly et al., 2019). Hence, to bridge the identified research gap and foster a comprehensive understanding of the research field concerning SCPs, this paper develops a SCP taxonomy.
In doing so, we decided to use an inductive-deductive research approach following Nickerson et al´s. (2013) taxonomy development method combined with Wolfswinkel et al. (2013) guidelines for systematic literature reviews. Based on a systematic literature review on SCPs, we develop a SCP taxonomy that comprises 4 meta-dimensions and 12 dimensions. This taxonomy contributes to the literature by providing a conceptual basis for understanding and differentiating SCPs. Thus, the taxonomy enables future research and theorizing of SCPs by establishing comparability among different SCP types. After this introduction, we outline the research background on SCs and SCPs. The third section describes our literature search and taxonomy building before we outline, in section four, the developed SCP taxonomy. We close the article by discussing the SCP taxonomies contribution, limitations, and avenues for future research.

2 Research Background

Over the past two decades, SCs have garnered considerable research and policy interest. Although extensively discussed in the literature, the term SC remains a concept with blurred boundaries and varying interpretations (Nastjuk et al., 2022). SCs are a growing phenomenon in urban development, leveraging ICTs to surge the human- and social capital to fuel sustainable economic growth and improve the QOL of their residents (Yigitcanlar et al., 2018). SC phenomena rely on SCP deployment, as a backbone for collecting, processing, and analyzing urban data streams from peripheral devices and systems within a city (Cheng et al., 2015; Gaur et al., 2015). In that vein, previous research investigated the distinct requirements for the design of SCPs. In the literature, the requirements are structured into functional and non-functional requirements (Da

Cruz et al., 2018; Shapsough & Zualkernan, 2019). The functional requirements mentioned most often in the literature are security and privacy, data management, standardization, interfaces, data visualization, and resource discovery (Fersi, 2015; Mijuskovic et al., 2021; Oliveira et al., 2016). On the other hand, non-functional requirements encompass interoperability, scalability, real-time processing, timeliness, modularity, context awareness, and quality of service (Agarwal & Alam, 2020; Al-Fuqaha et al., 2015; Mijuskovic et al., 2021). However, the requirements can broadly vary based on the distinct type of SCP they study. For instance, due to the lack of a uniform standard, Koo and Kim (2021) highlight the interoperability issues for horizontal SCPs. Advanced interoperability is crucial for horizontal SCPs, which are designed to be flexible, scalable, and capable of integrating diverse applications from various domains (Mijuskovic et al., 2021). In contrast, vertical SCPs differ in terms of scope, functionality, and intended use. Identifying valid requirements for diverse application scenarios on SCPs is challenging due to the heterogeneous array of applications and respective SCP types (El-Ghalayini & Al-Kandari, 2020; Zanella et al., 2014). Therefore, major issues arise in identifying and considering relevant requirements for different types of SCPs. Existing classifications, e.g. Santana et al. (2018), suggest SCP types by enabling ICTs: Cyber-Physical Systems, IoT, Big Data, and Cloud Computing. This classification can offer instructions for implementing SCPs based on these ICTs but lacks insights into SCP characteristics or types. That is, SCP requirements stem not only from the underlying ICT but the broader context of the application.
Hence, while important features of SCPs are well understood, we lack a systematic classification of SCPs (Santana et al., 2018). We argue that the development of a taxonomy is necessary to effectively highlight and examine the SCP phenomenon from a systematic perspective. A taxonomy of SCPs illustrates the distinct and multifaceted characteristics and enables the potential for new approaches for platform design, patterns, associations, and causal relationships (Lueg et al., 2022; Schermuly et al., 2019). Moreover, it captures transparency and enables an assignment of the requirements to the respective SCP types. Highlighting the diverse dimensions and characteristics of SCPs may facilitate further, leading to a deeper understanding and comprehensive analysis of the phenomenon (Nickerson et al., 2013).

3 Methodology

3.1 Data collection & data analysis

We conducted a systematic literature review based on Wolfswinkel et al. (2013) and followed Nickerson et al.'s (2013) taxonomy development approach to assemble a SCP taxonomy. This method has been widely recognized in IS research and includes predefined phases for creating a structured taxonomy (Bailey, 1994). Taxonomies embody a valid instrument to guide various disciplines to "*bring order to complex areas*" (Nickerson et al., 2013, p. 535). This is done by categorizing dimensions or traits and highlighting similarities among a subject being studied (Bailey, 1994).

The data collection is based on a systematic literature review of SCPs and is consistent with the suggestions of Wolfswinkel et al. (2013). First, we conducted various search inquiries to obtain a common understanding of the phenomenon in the literature. The data collected in the databases utilized the search strings shown in Table 1. We built these search strings around the terms "Smart City" and synonyms for "Platform", and "Requirements" as well as the application context of SCs. We deliberately decided to not include search terms that refer to concepts related to SCs and SCPs (e.g., Big Data) to narrow the search results to existing literature that may deal with these related concepts but only within the context of SCs and SCPs.

Table 1. Search Strings for Data collection

Search String	Applied Database
"Smart City" AND "Platform" OR "Middleware" OR "Data Platform" OR "Smart City Platform" AND "Characteristics" AND "Requirements"	Web of Science, ACM Digital Library, IEEE, AIS Electronic Library, ScienceDirect, and Google Scholar
"Smart City Service" OR "Smart City Application" AND "IoT"	
"Smart City" AND "Service" OR "Application" AND "IoT"	

This yielded 623 papers initially. In the beginning, we filtered the articles by examining the title and the abstract. Afterward, we read the full paper and eliminated papers that were not confirmed with the subsequent criteria. The focus is on SCPs, thus, we excluded papers that did not entail detailed information about the key characteristics of SCPs. Articles that applied a vague definition of SCPs, were also excluded. Second, only articles with a focus on SCPs were considered. Hence, solely papers restricted to the SC phenomena were excluded. In addition, due to the interwoven relationship between IoT and SCs, papers about IoT platforms in the context of SCs were considered as well. Furthermore, only articles written in English are considered. Lastly, a forward and backward search was performed to enrich the literature sample. We outline the article selection and filtering process in Figure 1. During the data collection, we gathered information including the type of articles. We differenced between scientific papers, and gray literature (e.g., practice reports or whitepapers). In general, whitepapers are characterized by an elaboration of a case and the gathered experience. In total, 50 articles form the baseline for our study.

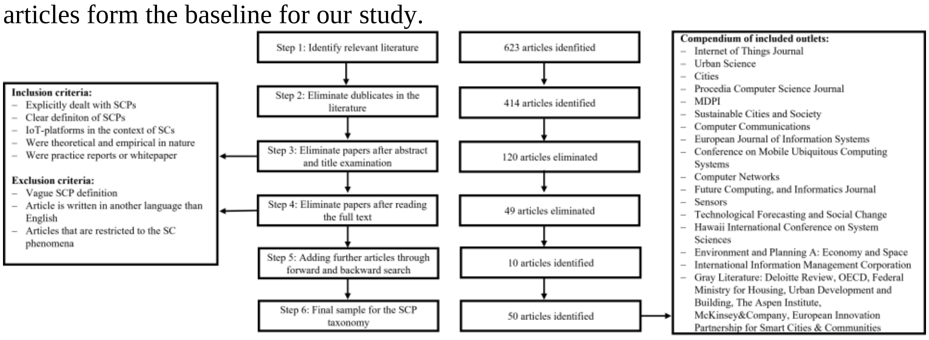

Figure 1. Article Selection & Filtering Process

3.2 Taxonomy development

The taxonomy development process followed the iterative steps outlined by Nickerson et al. (2013). In the beginning, we determined our meta-characteristic. The meta-characteristics represent the basis for selecting the characteristics of the taxonomy (Nickerson et al., 2013; Pinto & Martins, 2004). As our goal is to typify SCPs, we established the following meta-characteristic: "Key characteristics of SCPs". Accordingly, we devised objective and subjective ending conditions based on Nickerson et al. (2013) advocacy. We developed the following objective ending conditions: (1) All objects have been thoroughly scrutinized, (2) At least one object is classified under every characteristic of every dimension, (3) No new dimension was added in the last iteration and (4) Every dimension is unique within its dimension and is not repeated (Nickerson et al., 2013). In addition, Nickerson et al. (2013) suggest the ending condition that all characteristics are mutually exclusive. However, crafting our taxonomy, we encountered instances when restricting the taxonomy to mutually exclusive characteristics lead to information loss (Berger et al., 2018). Furthermore, removing these characteristics would contradict the motive of taxonomies to be sparing and holistic (Bailey, 1994; Nickerson et al., 2013). Thus, we decided against this ending condition. Lastly, we determined subjective ending conditions – comprehensive, extendible, explanatory, concise, and robust – following Nickerson et al. (2013).

The taxonomy development comprised three iterations. Given the body of prior work on SCPs, we chose an empirical-to-conceptual (E2C) approach and first analyzed the scientific papers (Nickerson et al., 2013; Pinto & Martins, 2004). Coding these papers, we identified common characteristics of SCPs and ordered them hierarchically (Gioia et al., 2013). Extending our analysis to non-scientific papers, we concluded that the taxonomy misses the defined ending conditions. We thus conducted a second iteration. In the second iteration, we chose the conceptual-to-empirical (C2E) approach (Nickerson et al., 2013; Pinto & Martins, 2004). We thus analyzed the identified whitepapers continuing the coding schema from the first iteration. This produced validation of existing characteristics and dimensions but also extension and specification of the taxonomy. Since we identified new dimensions and characteristics, we conducted a third iteration (Nickerson et al., 2013).

In the third iteration, we conducted an E2C approach and analyzed the entire literature sample again. Since we analyzed all items and did not identify additional characteristics or dimensions, we concluded that the taxonomy meets the ending conditions (Nickerson et al., 2013). Lastly, we evaluated the taxonomy's functionality by applying it to the Smart Santander case study by Sanchez et al. (2014) and Santana et al. (2018).

4 Smart City Platform Taxonomy

In the following, we elaborate on the taxonomy for SCPs in detail. Table 2 displays the final version characterizing SCPs. Based on our implied theoretical lens, the taxonomy consists of 12 dimensions within 4 meta-dimensions. The right column, displays, whether the characteristics are mutually exclusive (E) or non-mutually exclusive (N).

4.1 Meta-Dimension Smart City Platform Strategy

The strategy pays specific attention to the approach and strategic alignment to initiate SCPs and is divided into four dimensions (Bagheri et al., 2021). The dimension of **Platform Positioning** regards the holistic nature of SCPs. This dimension encompasses two distinct modes. First, SCPs can embody a specialized platform consisting of multiple fragmented systems (M. Khan et al., 2017; Kitchin & Moore-Cherry, 2021). Specialized SCPs typically focus on a narrow set of services or functions and rely on specific data sources or stakeholders (Anttiroiko, 2016; Stehlin et al., 2020). Common specialized SCPs include transportation, energy, and health platforms (Anttiroiko, 2016; Bibri & Krogstie, 2020; Massana et al., 2017). However, specialized SCPs may encounter challenges in interoperability, scalability, and sustainability, and require coordination and integration with other platforms and stakeholders (Bibri & Krogstie, 2020; Correia & Wünstel, 2011; Koo & Kim, 2021) Second, SCPs represent one central system called integrative. This requires interoperable interfaces, open standards, and common governance frameworks that enable different SCPs to communicate and collaborate (Correia & Wünstel, 2011; Koo & Kim, 2021; Zanella et al., 2014). Therefore, empowering a specialized SCP to evolve into an integrative SCP represents a key strategy for creating a more integrated SC (Correia & Wünstel, 2011; F. Khan et al., 2022; Zanella et al., 2014) The **Value proposition** dimension refers to the benefits or advantages that SCPs offer to their users and stakeholders (Frow et al., 2014). Bibri and Krogstie (2020) argue that the London DataStore, based on raw urban data, can engage developers to create disruptive apps. In exchange for the data and platform usage, the operator receives a certain fee. In the literature, it is called Platform-as-a-Service (PaaS) (Ray, 2016; Santana et al., 2018). Highly related to PaaS is Software-as-a-Service (SaaS). The main difference between those two is, that SaaS provides customers access to prebuild software applications, while PaaS provides a platform for developers to build and deploy their applications (Ballon et al., 2011; Mineraud et al., 2016). Due to different priorities and issues, the choice of which value proposition SCPs choose is strongly influenced by the **Application Domain** for which it is being designed. Based on the literature we follow Giffinger and Gudrun (2010) and consider six SCP application avenues: mobility, people, living, environment, economy, and public administration. SCPs in the mobility domain focus on optimizing and improving the existing transportation infrastructure within a city (Alavi et al., 2018; Hunter et al., 2019). While the people domain refers to the human and social needs of citizens, the living domain relies more on the physical and environmental components of city life (Kaluarachchi, 2022). SCPs in the environmental domain refer to managing and mitigating environmental risks and improving the sustainability of urban environments (Giffinger & Gudrun, 2010). Further, the economy domain emphasizes supporting economic growth in urban areas (Giffinger & Gudrun, 2010; Kaluarachchi, 2022). In addition, SCPs in the public administration domain focus on improving the efficiency, transparency, and effectiveness of government operations and services (Anttiroiko et al., 2014; OECD, 2019). The previously mentioned application domains are in line with several other authors (Čukušić et al., 2019; Kaluarachchi, 2022; OECD, 2019). Finally, the dimension of **Software Access** concerns the ability or permission granted to users and stakeholders to interact with, utilize, or modify the software or platform. For instance, the City of Barcelona provides the open-source platform Sentilo, to collect, aggregate, and analyze the deluge of urban data (Bibri & Krogstie, 2020). However, the provision of a proprietary platform is also possible (Woods & Citron, 2020).

4.2 Meta-Dimension Smart City Platform Stakeholders

This meta-dimension defines the distinct components and traits of stakeholders that make up SCPs and interact with each other to create the whole system (EIP-SCC, 2016; Lyytinen & Newman, 2008). The dimension **Platform Owner** regards the question of who owns the platform. Santana et al. (2018), Lee et al. (2014) and Anttiroiko et al. (2014) note that SCPs can be owned by governments, private companies, non-governmental organizations (NGOs), or by private-public-partnerships (PPPs). Each ownership model can have significant implications on the requirements of SCPs. For instance, while private ownership of a SCP may prioritize profit-making, a government owner may emphasize stricter regulations and oversight to ensure transparency and equal access (Anttiroiko et al., 2014; Mineraud et al., 2016). The dimension of **External Partners** relates to the engagement of actors beyond the city government who have a direct or indirect impact on SCPs and their operations (Ballon et al., 2011). On the one hand, actors outside of the city government, such as private sector companies, NGOs, and academic and research institutions support the development and implementation of SCPs (Bagheri et al., 2021; Sanchez et al., 2014). Some cases emphasized that external partners are engaged in a long-term business relationship and provide the whole IT-Infrastructure for SCPs. This expression is entitled an open platform (Ballon et al., 2011; Bouskela et al., 2016). In contrast, a closed platform is characterized by no involvement of external stakeholders (Ballon et al., 2011; Hunter et al., 2019). Finally, the dimension **Technical Operator** is closely related to the previous dimension. It relates to the complex and multifaceted right to control and administrate SCPs. Two significant approaches could be identified. First, several cases highlighted that the operator of SCPs also embodies the provider of the IT infrastructure (Deloitte, 2020). This can occur for example when the city takes on both roles. This scenario is entitled as a single operator. Second, the operator of SCPs may contract with a private company or consortium to provide the IT infrastructure. Thus, we assume that tightly coupled business relationships between two distinct stakeholders lead to a multi-operator scenario (Deloitte, 2020; Javed et al., 2020; J. Lee, 2019).

4.3 Meta-Dimension Technical Infrastructure

The meta-dimension technical infrastructure encompasses the underlying infrastructure and attributes of the utilized data on SCPs (Mineraud et al., 2016). The dimension **Development Approach** outlines different methods to design and implement SCP initiatives (Ballon et al., 2011). We observed primarily citizen-centric approaches, which highlight the necessity to actively engage the citizens in the development process of SCPs to address their needs (Bollier, 2016; von Radecki & Dieguez, 2022) Frequently mentioned as well, was the technology-centric approach. While a citizen-centric approach emphasizes the needs and perspectives of citizens, a technology-centric approach emphasizes the usage of technology to solve city challenges and streamline the performance of city services (Belli et al., 2020; Chen & Chan, 2023; von Radecki & Dieguez, 2022). City services constitute digital tools designed to enhance the effectiveness and accessibility of public services in urban areas (Bollier, 2016). Further, information- and institution-centric were also identified. While an information-centric SCP development approach outlines the means to collect, analyze and provide data to improve decision-making, institution-centric SCPs address the government institution's perspective such as city departments and agencies, leading to more efficient and effective management of the city (Belli et al., 2020; Woetzel et al., 2018). The Dimension **Data Format** pays attention to the structure and organization of data on SCPs, including the arrangement of data so that it can be easily understood and processed. Through our analysis, we identified four different data formats on SCPs. First, numerical data format relies on data that consists of numbers, such as integers, decimals, or floating-point numbers. The numerical data format can be used to represent a wide range of information, including measurements, quantities, and statistical data (Eggers et al., 2017). Second, textual data refers to data that consist of textual information, such as words, sentences, or paragraphs (Eggers et al., 2017). Third, audio and video data format relates to how audio and video data is represented and stored in a digital format. Audio and video data can be captured from a variety of sources such as microphones and cameras. Further, both can be stored in a variety of file formats, which depends on the nature of audio and video data and the requirements of the application (Al Nuaimi et al., 2015; Syed et al., 2021). In total, the data format used in SCPs is a significant component in platform design and implementation, as it can impact the platform requirements interoperability, security, and performance (Al Nuaimi et al., 2015; Eggers et al., 2017; Syed et al., 2021). Finally, the dimension **Cloud Mode** describes how SCPs are deployed and managed in a cloud computing environment (Bibri, 2020; Ray, 2016). A public cloud may be a suitable option for SCPs that require scalability, cost-effectiveness, and access to a wide range of cloud services and applications. Further, public clouds offer the advantage of economies of scale, access to a vast pool of computing resources, and the ability to scale up or down quickly based on demand (Nakhuva & Champaneria, 2015; Ray, 2016). Thus, it makes it easier for SCPs to add new features and services. However, a public cloud may not be suitable for SCPs that require high levels of security, data privacy, and customization. In that vein, a private cloud may be a better option for SCPs that require higher levels of security, data privacy, and customization (Woetzel et al., 2018). Private clouds offer the advantages of dedicated infrastructure, exclusive access to resources, and a higher level of control over the infrastructure (Syed et al., 2021; Zhang et al., 2017). However, private clouds provide limited scalability capabilities and are less cost-effective than public clouds. Therefore, a hybrid cloud model is possible as well (Mineraud et al., 2016; Santana et al., 2018). This setting provides SCPs the ability to leverage the scalability, agility, and cost-effectiveness of public cloud resources, while maintaining control over sensitive data in the private cloud (Ballon et al., 2011; Bibri, 2018; Mineraud et al., 2016). Overall, the choice between public-, private- and hybrid cloud model, depends on the specific needs and requirements of SCPs.

4.4 Meta-Dimension Governance

The meta-dimension governance describes a set of principles, policies, and processes that govern the use and management of SCPs (Barns, 2018). Recently, **Cybersecurity** on SCPs surged in significant interest and attention and refers to maintaining the confidentiality, truthfulness, and availability of information (Von Solms & Von Solms, 2018). During our analysis of SCPs, we identified that the value of cybersecurity primarily unfolds across the trifecta of encryption, anonymization, and access control. Encryption highlights the usage of cryptographic techniques to secure sensitive data that is transmitted and stored within SCPs (Fortino et al., 2022). It can be implemented in several areas and represent a crucial mechanism to maintain trust among the stakeholders (Fortino et al., 2022; Zhang et al., 2017). The anonymization method contributes to increasing the public trust in SCPs and is characterized by removing any identifiable information from the collected data such as name and address (Lupi, 2019; Mineraud et al., 2016). In addition, several cases illustrated the implementation of access controls to manage access to sensitive data, resources, and functionalities within SCPs (Ballon et al., 2011; Mineraud et al., 2016). Overall. the elaborated cybersecurity techniques aim to foster acceptance and maintain trust in SCPs (Lupi, 2019; Mineraud et al., 2016). Lastly, the **Data Management** dimension relates to the processes and operations of SCPs performed on the data collected from several sources within the city (Barns, 2018; Mineraud et al., 2016; von Radecki & Dieguez, 2022). Managing this data effectively is crucial for developing and implementing solutions that address the issues of the city (Da Cruz et al., 2018; Santana et al., 2018). As noted by several authors data management in SCPs can be categorized into eight main areas. First, the collection of data involves various data sources, such as sensors, cameras, and other IoT devices (von Radecki & Dieguez, 2022). SCPs leverage storage systems, such as databases to store and manage the collected data in a way that is organized, secure, and easily accessible. Predominantly, cloud environments are used for the storage of urban data streams (Gaur et al., 2015; Mineraud et al., 2016). Afterward, data aggregation refers to the process of combining multiple data points into a single summary (Angelidou et al., 2018; Qiu et al., 2019). The main added value of data does not come from aggregating data, but rather from data analysis. Data analysis refers to the process of examining and interpreting data to extract useful information and insights (Correia & Wünstel, 2011; Syed et al., 2021). Accordingly, features for visual representations, as well as simulations of the extracted information, are two important auxiliary instruments on SCPs to understand and interpret data and enable stakeholders to make informed decisions (Correia & Wünstel, 2011; Gaur et al., 2015). SCPs can provide access to this extracted information and share it with others (Bibri & Krogstie, 2020; Kim et al., 2020). In that vein, data transmission is a critical component enabling the sharing of information. The transmission process may be affected by several factors such as the type of encoding and decoding methods used on SCPs (Correia & Wünstel, 2011).

Table 2. Taxonomy for Smart City Platforms

Dimensions		Characteristics								E/N
Smart City Platform Strategy	Platform Positioning	Integrative				Specialized				E
	Value Proposition	Software-as-a-Service				Platform-as-a-Service				E
	Application Domain	Public Administration		Living	Economy	People	Mobility	Environment		N
	Software Access	Open Source				Proprietary				E
Smart City Platform Stakeholders	Platform Owner	Government		Private Company		Non-Governmental Org.		Private-Public Partnership		E
	External Partners	Open Platform				Closed Platform				E
	Technical Operator	Single Operator				Multi-Operator				E
Technical Infrastructure	Development Approach	Citizen-centric		Technology-centric		Institution-centric		Information-centric		E
	Data Format	Numerical	Textual	Audio		Video		Geospatial		N
	Cloud Mode	Public Cloud			Private Cloud		Hybrid Cloud			E
Governance	Cybersecurity	Encryption			Access Control		Anonymization			N
	Data Management	Collection	Aggregation	Analysis	Sharing	Transmission	Visualization	Simulation	Storage	N

4.5 Taxonomy Application

In this section, we apply the SCP taxonomy to the Smart Santander platform (SSP) presented by Sanchez et al. (2014) and Santana et al. (2018). Table 3 summarizes the taxonomy's application to this case. This application illustrates the usefulness of the taxonomy to typify SCPs.

Smart City Platform Strategy. The SSP represents an integrative system. Moreover, both articles display that the SSP captures value based on a SaaS business model (Sanchez et al., 2014; Santana et al., 2018). Being integrative, the SSP addresses various application domains. These are in the living, mobility, and environmental domains. Sanchez et al. (2014) and Santana et al. (2018) did not emphasize the software access factor in their articles. However, Sanchez et al. (2014) highlight that the purpose of the SSP is the development of novel IoT-enabled applications. Based on this, we assume that the platform is open and accessible to the public, allowing developers and researchers to access and use the platform's data and services to develop new applications and services. Therefore, we deduce that the SSP constitutes an open-source platform to enable collaborative solutions.

Smart City Platform Stakeholders. The University of Cantabria collaborated in the development and implementation of the SSP with both private and public organizations, which speaks to PPP ownership (Sanchez et al., 2014; Santana et al., 2018). The involvement of external partners (e.g., private companies, agencies) makes the SSP an open platform (Sanchez et al., 2014). Sanchez et al. (2014) and Santana et al. (2018) reveal little about the technical operator. Since ownership is PPP, we assume that the IT provider differs from the SSP operator.

Technical Infrastructure. The Smart Santander testbed represents a research and technology-driven facility. This reflects a technology-centric development approach. The SSP primarily collects urban data streams comprising numerical and geospatial data formats (Santana et al., 2018). The SSP is hosted on a hybrid cloud (Sanchez et al., 2014; Santana et al., 2018).

Governance. The SSP implements encryption, access control, and anonymization as measures for cybersecurity (Santana et al., 2018). Both articles characterize the SSP's data management as involving collection, analysis, visualization, storage, and sharing of data (Sanchez et al., 2014; Santana et al., 2018).

Table 3. The Smart Santander Platform

	Dimensions	Characteristics								E/N
Smart City Platform Strategy	Platform Positioning	Integrative				Specialized				E
	Value Proposition	Software-as-a-Service				Platform-as-a-Service				E
	Application Domain	Public Administration		Living	Economy	People	Mobility	Environment		N
	Software Access	Open Source				Proprietary				E
Smart City Platform Stakeholders	Platform Owner	Government		Private Company		Non-Governmental Org.		Private-Public Partnership		E
	External Partners	Open Platform				Closed Platform				E
	Technical Operator	Single Operator				Multi-Operator				E
Technical Infrastructure	Development Approach	Citizen-centric		Technology-centric		Institution-centric		Information-centric		E
	Data Format	Numerical	Textual	Audio		Video		Geospatial		N
	Cloud Mode	Public Cloud			Private Cloud		Hybrid Cloud			E
Governance	Cybersecurity	Encryption			Access Control		Anonymization			N
	Data Management	Collection	Aggregation	Analysis	Sharing	Transmission	Visualization	Simulation	Storage	N

5 Discussion, Limitations, and Future Research

Our conducted study was motivated by our observation that SCs gain much attention in recent years but lack a systematic framework about what SCPs truly are and how they vary. Already existing research primarily addresses specific requirements of SCPs or emphasis the architecture without a profound classification of characteristics (Koo & Kim, 2021; Santana et al., 2018). This hinders the comparability of existing SCPs and the possibility to deduce conceptual abstractions from the result (Gregor, 2006). In addition, we challenge the customary approach of investigating and applying the phenomena of SCPs through commonly held and simplified assumptions, which presume the clarity and absence of difficulties within the SCP construct (Lueg et al., 2022).

We argue that a profound classification is necessary for IS researchers to assemble aggregative knowledge about SCPs; the initial point for platform design, the explanation of interdependencies, assessment of risks, patterns, and characteristics (Schermuly et al., 2019). The conducted study provides this systematic classification of SCPs in the form of a taxonomy following Nickerson et al. (2013) based on a systematic literature review. Therefore, we contribute to academia by providing a framework based on the existing knowledge about the characteristics of SCPs. Our developed taxonomy distinguishes SCPs based on 4 meta-dimensions and 12 related dimensions.

By developing the taxonomy about the characteristics of SCPs we seek to fill this gap and thereby make a relevant contribution in the following respects; First, based on our taxonomy we structure the broad and complex knowledge about SCPs and provide a profound scheme of the multifaceted character of SCPs. By considering various layers, we go beyond current classifications and tackle a phenomenon that is characterized by its interdisciplinary and intricate nature (Lohoff, 2022). Further, thereby, we can gain a profound understanding of the unique dynamics of SCPs and their necessary traits to attract further stakeholders to join the ecosystem. Second, we contend that our taxonomy aids in exploring SCP initiatives, as it offers means of classification and enables a structured examination of a wider context. Lastly, our structured classification enables comparability and captures transparency about what SCPs are and how SCPs conceptually differ, thereby we can identify and assign the relevant requirements for each respective SCP type. In that vein, we can make theoretical generalizations and provide the baseline for the development of better SCPs in the future.

From the practitioner's lens, the devised taxonomy outlines, that SCPs are not linear nor is there an archetypal model. Thus, practitioners can harness this taxonomy as an instrument to analyze and distinguish SCPs. A better understanding of embedded SCPs and their requirements supports cities to surge human- and social capital, fostering sustainable economic growth, and improving dwellers' QOL (Hollands, 2008). Furthermore, the taxonomy embodies a beneficial instrument to ease and improve the development of SCPs, due to the interwoven and complex associations (Lueg et al., 2022).

Nevertheless, this study faces some limitations. First, due to the static nature of our taxonomy and the rapidly evolving field, our systematic literature review only offers a snapshot of SCPs. Hence, we cannot guarantee the exhaustiveness of the dimensions and characteristics. Second, we did not scrutinize possible interrelationships between single characteristics and dimensions. Third, we acknowledge that some dimensions, e.g., cybersecurity, may reveal little benefit in distinguishing different SCP types, because of the nature of their characteristics. That is, all SCPs should have the mentioned cybersecurity measures. However, we kept this dimension to highlight that cybersecurity is critical and that future work on SCPs should reveal more detailed information on their cybersecurity to allow for better differentiation of, e.g., implementations of access control. Finally, even though we followed Nickerson et al. (2013) guidelines and conducted an E2C and C2E approach, additional proof with empirical cases is needed to verify the taxonomy. Future research might concentrate on the deduction of SCP archetypes to permit an underlying classification of SCPs. By examining the identified archetypes, it could be possible to further explore if certain archetypes exhibit higher levels of efficacy than others, thus yielding to the derivation of design principles for SCPs (Gelhaar et al., 2021). Furthermore, scrutinizing the relationships between each dimension and their related characteristics may provide further insights into the design and the performance of SCPs.

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