Evaluation of Smart City Models: A Conceptual and Structural View

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Abstract: With the rapid development of smart cities, there has been a variety of smart city models that are proposed to facilitate the smart city design and service architecture. Meanwhile those smart city models also create complexity to follow the models and it is difficult to observe how the models can work collaboratively as well as how to possibly improve the models. Therefore, this paper firstly classifies the smart city models with a conceptual and structural view, where the conceptual models focus on the interactions of components and the structural models are featured by layers with processes. Based on the model classification, the paper further evaluates the models with service structure, interoperability, multi-context and adaptability. The evaluation results can be used to compare, select and improve the smart city models and service design.

1 INTRODUCTION

Smart city has a very wide range of stakeholders ranging from citizens, organizations to municipalities. This leads to the result that smart city initiates a variety of concepts with diverse definitions (Stepánek et al., 2017; Dragoicea et al., 2020). From the organizational perspective, today's organizations intend to be flexible in organizing their operations, services, technological solutions, to respond quickly to any changes and challenges, and improve the organizational resources allocation continuously(Buhnova et al., 2022; Mbarek et al., 2021).

Throughout the last decade, different works have viewed the smart city from various perspectives, and derived different definitions for smart city (Piro et al., 2013; Desouza and Flanery, 2013; Lee et al., 2014). Most of the works are stressing the importance in a local context (Neirotti et al., 2014; Wey and Hsu, 2014) or analyzing existing conceptual views on smart city (Chourabi et al., 2012). For example, from the view of municipality, it is critical for municipalities and city planning experts to understand versatile aspects of the smart city management, including the structure and composition of smart cities, their interrelationships, and how they interact (Ge et al., 2019; Trang et al., 2019). However, gathering this information in a comprehensive and orderly manner is a significant challenge for them, and due to the incompleteness of the information, it often affects the quality of their decisions and makes it difficult to implement smart city-appropriate management (Anthopoulos et al., 2019).

To understand smart city, various stakeholders may name or interpret one thing differently, especially with terminology. The way to construct Smart City under one dominant domain like Smart Government (Anthopoulos et al., 2021) or urban development (Liu et al., 2020) means losing the information and links to other domains that might be critical for Smart City development (Bastidas et al., 2021; Bangui et al., 2018). Therefore understanding this diverse terminologies will provide an comprehensive view for the diversity of smart cities and how they interact with each other (Yang et al., 2019). Smart cities need to reflect in their smart city management and operations the ability to respond and adapt to changes at all levels of cities with the rapid development of technology (Walletzký et al., 2020; Walletzký et al., 2019). The development of a smart city model in line with this situation is important for the development of a smart city. Thus, it is important to implement a smart city model that is compatible, resilient, and adaptable (Lom and Přibyl, 2020).

This paper is therefore to determine whether existing smart city models meet the requirements of smart cities and provide an evaluation study to help develop a model that meets those requirements. In this study, we will select nine smart city models and compare them based on "structure", 'interoperability", "multi-contextual view" and "adaptability" to see if they

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meet today's smart city requirements. The results of this study will determine whether the existing models meet the needs and will serve as a basis for the development of a suitable model.

The rest of the paper is organized as follows. Section 2 selects nine smart city models that are further divided into conceptual models and structural models. Section 3 evaluates the models based on four criteria, which are structure, interoperability, multi-contextual view and adaptability. Section 4 concludes the paper and highlights the future research.

2 SMART CITY MODELS

To find the papers that are focused on a structural and conceptual model of smart city, we have used Google Scholar and searched the literature by using the following keywords: smart city, conceptual model, structural model, and architecture. We considered that Google Scholar is more up-to-date with including new papers and combining the paper sources from various libraries such as IEEE, ACM and Springer. Based on the research results we have manually selected the 9 most relevant papers and divided them into two groups: conceptual and structural. The conceptual models focus on the smart city framework and the interactions between different conceptual terminologies. On the other hand, the structural models are mostly layer-based and focused on different stages of smart cities.

2.1 Conceptual Smart City Models

(Nam and Pardo, 2011) aims to suggest a framework connecting conceptual variants of the smart city label, key elements for being a smart city, and strategic principles for making a city smart. For defining smart city, a variety of the labels can be categorized into three dimensions: technology, people, and community. The conceptual variants are mutually connected with substantial confusion in definitions and complicated usages rather than independent on each other.

From the discussion of conceptual variants of smart city that set of fundamental factors which make a city smart, the author identifies and clarifies key conceptual components of smart city, and recategorises and simplifies them into three categories of core factors: technology (infrastructures of hardware and software), people (creativity, diversity, and education), and institution (governance and policy). Given the connection between the factors, a city is smart when investments in human/social capital and IT infrastructure fuel sustainable growth and enhance the quality of life, through participatory governance.

The author offers strategic principles for making a city smart in order to realize the various visions specified for diverse policy domains, aligning to the three categories of core components. First, integration of Technology Factors: integrates technologies, systems, infrastructures, services, and capabilities into an organic network that is sufficiently complex for unexpected emergent properties to develop. Second, learning for Human Factors such as social learning and education. And third, governance of Institutional Factors such as collaboration, cooperation, partnership, citizen engagement, and participation.

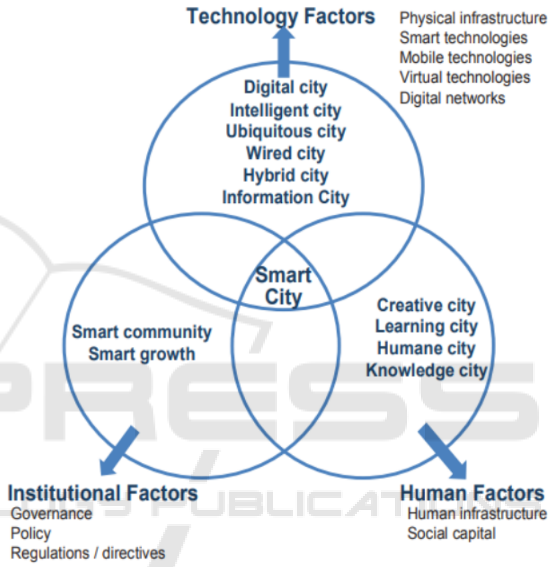

Figure 1: Fundamental Components of smart city (Nam and Pardo, 2011).

The research objective of (Hämäläinen and Tyrväinen, 2018) is to present a smart city conceptual model (SCCM) that assists cities and their stakeholders to carry out robust smart city initiatives and enhance sustainable smart city ecosystem design and development. Foundation for SCCM is derived from the systematic literature review of the smart city ecosystems and value networks. SCCM originates from a perception that design and management of complex smart city is not a trivial task and many smart city initiatives have failed it due to weak smart city governance, ecosystem orchestration and insufficient digital technology knowledge and capabilities. Thus, SCCM aims to clarify complex smart city governance, ownership, orchestration and decision-making procedures and advance technological compatibility and correct skills and resource allocation in cities. Furthermore, SCCM aims to provide tools to accelerate competitiveness, transparency and economic growth in cities.

The author proposed a smart city conceptual model that aims to assist smart city practitioners to form long-term smart city vision and strategy, facilitate the governance of the heterogeneous stakeholder relations and digital technologies, and assist to evaluate risks and funding needs. Smart city conceptual model considers four primary dimensions: strategy, technology, governance and stakeholders. Each primary dimension is complemented with sub-elements, which all together form meaningful interrelations and provide a comprehensive and systematic approach for the smart city design, development and implementation.

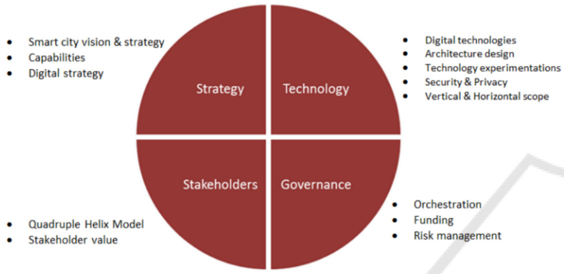

Figure 2: A conceptual model for the smart city design (Hämäläinen and Tyrväinen, 2018).

The aim of (Fernandez-Anez et al., 2018) is to facilitate the analysis of the complex and comprehensive smart city strategies designed by municipalities from an integrative perspective. This is used to develop a conceptual model capable of displaying an overview of the stakeholders taking part in the initiative in relation to the projects developed and the challenges they face. This model is also used to synthesise the opinion of different stakeholders involved in smart city initiatives and to compare their attitudes on the key projects implemented in a corresponding strategy.

The implementation of smart cities is still related to sector-specific and partial understanding, in part because of the limitations of governance and financing tools. It is necessary to bridge the gap between the theoretical comprehensive perspective and the sector-wide implementation of the smart city concept.

Stakeholders' involvement and engagement in decision-making is essential for Smart governance and it's the key element to becoming a smart city. However, stakeholders reveal different visions of the smart city in their discourses. There are also differences between the image of the smart city and its implementation and between the vision of the stakeholders in smart city development and the initiatives carried out. It can therefore be assumed that narrowing the gap between the stakeholders' vision of smart city initiatives and the implementation of certain projects may make a decisive difference to the success of smart city strategies.

The author further proposed a new model based on analysis of the usage of conceptual models in the scientific literature on smart cities. This research understands the smart city as an integrated and multi-dimensional system that aims to address urban challenges based on a multi-stakeholder partnership. The proposed conceptual model follows a comprehensive and integrative approach to smart cities that links the three main issues identified: (a) the key role of governance and stakeholders' involvement; (b) the importance of displaying a comprehensive vision of smart city projects and dimensions; and (c) the understanding of smart city as a tool to tackle the urban challenges. Finally, the three parts of the conceptual model are shown interrelated. The model is described from the centre to its outer limits, but not necessarily in a linear sequence, in order to aid its understanding.

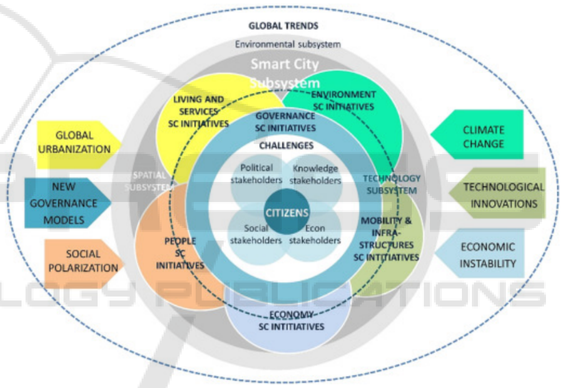

Figure 3: Smart city implementation and discourses: An integrated conceptual model (Fernandez-Anez et al., 2018).

(Arafah et al., 2018) aims to produce a new approach and concept, which is the "smart and resilient city". The authors explored five smart city models, and proposed a new model which contains especially resilience concepts in the context of natural disasters. The smart and resilient city model has 25 characters that are integrated and embedded within the scope of smart and resilient city concept: (1) the six characteristics (smart governance, smart economy, smart environment, smart living, smart mobile and smart people) can lead to a multi-dimensional strategy to synergize and support each other; (2) the four dimensions - the smart and resilient city concept; and (3) the components of the city are divided into physical and non-physical components: resources, processes, and technologies included into the physical group; people, institutions, and activities entered into non-physical groups. This model is developed to serve as a guide on building smarter and more resilient cities for planners and decision-makers, and to increase capacity responses from complex urban systems in facing climate change.

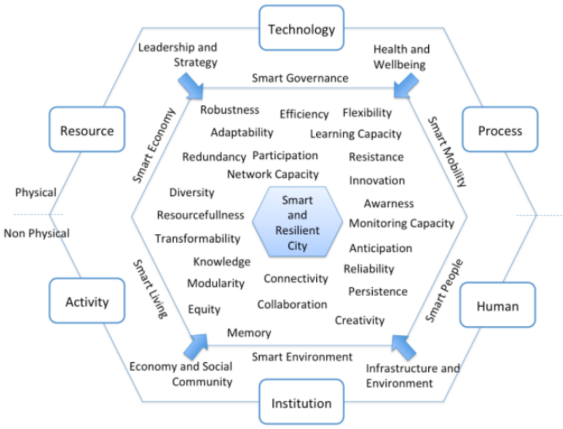

Figure 4: Smart and resilient city model (Arafah et al., 2018).

2.2 Discussions for Conceptual Models

Smart city conceptual models are multi-dimensional and are defined by the key components and factors that contribute to a smart city, and are designed to understand and manage those components and factors.

The first two models are similar, The first model shows the components that construct a smarter city, while the second model aims to improve the design and development of a smart city ecosystem and is represented by 4 dimensions with its sub-elements. These two models serve more as general outlines and are suitable for providing an overview for the components in a smart city.

The next two models are designed to help smart city planners and decision-makers build smarter and more flexible cities and support smart cities to accomplish the challenges they face. The third model is designed to show smart city stakeholders, their involvement in smart city initiatives, as well as smart city challenges. The fourth model is designed for serving as a guide for smart city planners and decision-makers on how to build smarter and more resilient cities, and to increase capacity responses from complex urban systems in facing the climate change.

For interoperability, some of these conceptual models of a smart city define the interoperability between the components that make up a smart city, but they are not clear. The interoperability in these papers is not detailed on how to help manage smart city components. For multi-contextual view. These conceptual models of smart cities are developed in general or in a specific context. In other words, they cannot be transformed into multi-contextual and cannot be changed. For adaptability, most of these models are not designed to be responsive to change. The fourth model may be able to respond to changes, but only partially.

Although these smart city conceptual models provide a comprehensive understanding of the components in a smart city, they stays in an abstract level. As such, it is important to propose a more detailed model to provide an understanding of the smart city services structure and implementation in order to manage smart city services in a multi-contextual environment.

2.3 Structural Smart City Models

(Chan and Paramel, 2018) proposes the model of smart city Ecosystem Frameworks. This model provides a comprehensive understanding of the smart city ecosystem framework as shown in Figure 5. The author develops this model for planning smart cities and considers that a vibrant and sustainable city is an ecosystem comprised of people, organizations and businesses, policies, laws and processes integrated together to create the desired outcomes such as government efficiency, sustainability, health and wellness, mobility, economic development, public safety and quality of life. This city is adaptive, responsive and always relevant to all those who live, work in and visit the city. A smart city integrates technology to accelerate, facilitate, and transform this ecosystem. The author defines four types of value creators in the smart city ecosystem: city, businesses and organizations, communities, and residents; and capability layers.

(Anthopoulos, 2015) aims to define a general smart city architecture, which serves governance purposes for innovation and sustainability, while it utilizes experiences from practical cases and corresponding theoretical context. The authors focused on answering the question ”What is the structure of a smart city architecture that could define a corresponding standard?” and proposed a generic multi-tier ICT architecture based on the analysis of smart city dimensions, categories, development stages, components, and existing smart city architecture approaches. The generic multi-tier ICT architecture for smart cities is proposed as follows:

- **Layer 1 - Nature Environment:** it concerns all the environmental features where the city is located such as landscape, rivers, lakes, sea, and forests.
- **Layer 2 - Hard Infrastructure (Non-ICT-**

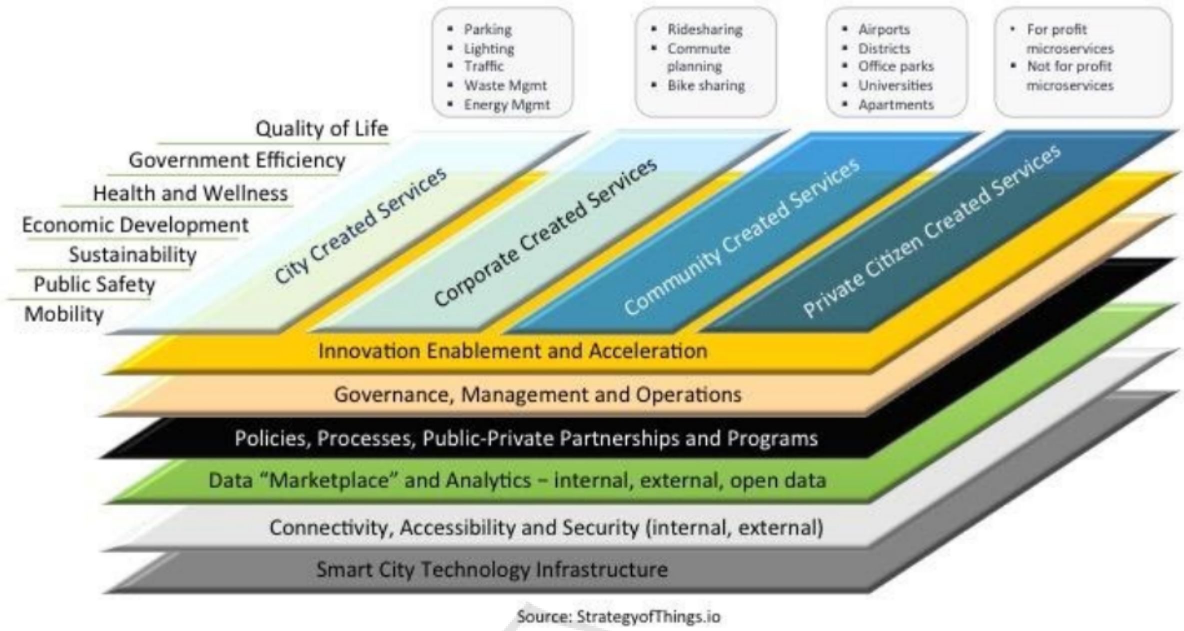

Figure 5: The smart city ecosystem framework (Chan and Paramel, 2018).

based): it contains all the urban features which have been installed by human activities and which are necessary for city operation (buildings, roads, bridges, energy-water-waste utilities etc.).

- **Layer 3 - Hard Infrastructure (ICT-based):** it concerns smart hardware that the SSC services are offered with (datacenters, supercomputers and servers, networks, IoT, sensors etc.).
- **Layer 4 - Services:** all the smart city services are grouped in the smart city sic dimensions and organized according to the international urban key-performance indicators.
- **Layer 5 - Soft Infrastructure**: individuals and groups of people living in the city, as well as applications, databases, software and data, with which the SSC services are realized.

(Deren et al., 2021) defines the concepts of digital twins and digital twin cities, discusses the relationship between digital twins and smart cities, analyzes the characteristics of smart cities based on digital twins, and focuses on the five main applications of smart cities based on digital twins. One of findings is the smart city operation brain (SCOB). The authors described the SCOB and its infrastructure that serves as the Public Information Cloud Service Platform.

Once the public information cloud service platform is established, the office of SCOB is able to start to operate, and the officials could use the applications on the platform to conduct management activities in the smart city. Figure 7 shows the structure of the public information cloud service platform. The platform is composed of an infrastructure layer, software development and operation platform layer, and an application layer. The platform uses infrastructure such as servers, networks, and sensor equipment to acquire data, and uses cloud infrastructure, data, platforms and software as services, and finally achieves the applications of cloud service platforms in various fields such as smart urban management, smart public security, and smart tourism. The platform can create an ecological chain for data collecting, processing, storing, cleaning, mining, applying, and feedback.

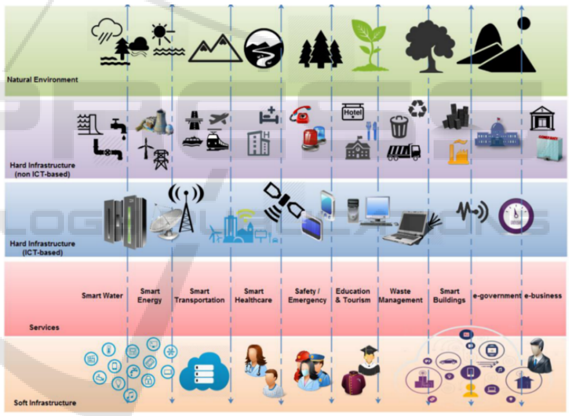

Figure 6: A generic multi-tier ICT architecture for smart city (Anthopoulos, 2015).

(Li et al., 2013) describes the key supporting technologies of smart cities (i.e. digital cities, Internet of Things, and cloud computing). From the geo-

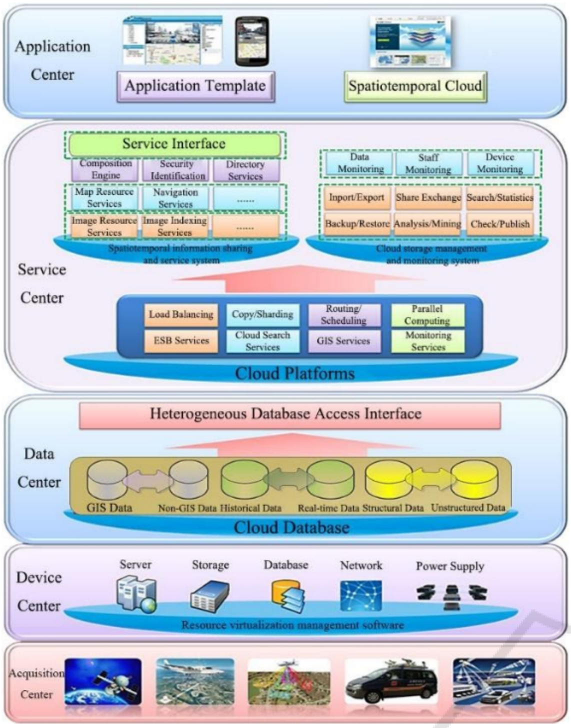

Figure 7: Schematic diagram of the structure of a smart city public information cloud service platform based on digital twins (Deren et al., 2021).

matics perspective, the fundamental and operational issues for smart city are addressed, including geo-referencing and 3D spatial-temporal modeling, integration of global position system (GPS), remote sensing and GIS in mobile platforms, devices and structures for ubiquitous sensing and communication, and service capabilities in cloud environments. The author defines the main framework of a smart city based on the Internet of Things. The Internet of Things shown in Figure 8 has a hierarchical structure of four layers: distributed sensor layer, ubiquitous network layer, service-oriented middle-ware layer and intelligent application layer.

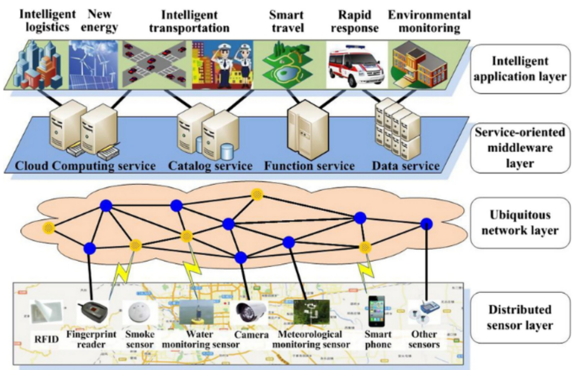

Figure 8: A framework of the smart city based on the Internet of Things (Li et al., 2013).

(Walletzký et al., 2018) identifies the benefits of an integrated view that not only interconnects the services, but also identifies joint layers that they rely on, which helps us to understand the impact of the underlying IT services and the infrastructure they rely on. At the same time, we extend our view to the Smart Citizen, who plays an essential role in the value creation process within the smart city.

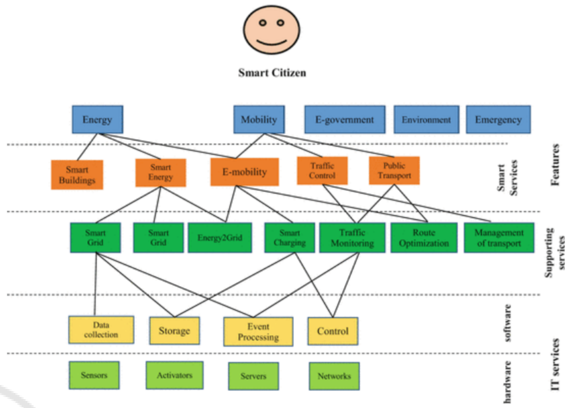

Figure 9: The structure of smart city layers (Walletzký et al., 2018).

2.4 Discussions for Structural Models

As for the structural model, most of the models have provided a comprehensive understanding of the smart city and its structure, which are built based on the information and communication technology infrastructure.

A majority of the models in this group provides a deep understanding of the structure of the smart city. Each model is usually built with 4-5 layers. The first two models show a smart urban environment and non-technological infrastructure than other models in this second group. For example, (Chan and Paramel, 2018) proposed a smart city ecosystem framework compared to other models, and provides important insights regarding how to build a smart city ecosystem through this model. It identifies the layers of smart city services in terms of service coverage, value and innovation, management and policy systems, data and privacy, security, and technology infrastructure, all of which together constitute a smart city ecosystem. The model is valuable in identifying the key components of a smart city ecosystem integrated with technology. However, we still need to identify the services that construct a smart city and how those services interconnect to create a smart city.

The smart city model in (Anthopoulos, 2015), unlike other models, is designed to create innovation and sustainability, with a smart city architecture that includes the natural environment and non-technological infrastructure. The model has layers called natural environment, services and soft infrastructure and we can obtain an understanding of the possible types that are covered by each layer.

The rest of the smart city models are based on information and communication technology infrastructure, and some of these models are more focused on specific technology features, such as IoT and Digital Twin. The common advantage of these models is that each model to some extent reflects the types of services provided by the smart city, and we are able to gain an understanding of the main types of services.

For interoperability – most of the models in this group provide insights of the types of smart city services, but most models do not fully show how those services are interconnected or connected to other layers. The last two models appear to be connected to the modules of the other layers. In particular, the latest model shows how it is connected to other layer services. However, this model does not show how the services in the same layer are interconnected.

From the multi-contextual view – these models are defined generally or from a specific perspective. In other words, the models are focused on multi-contextual views. However, the smart city consists of various stakeholders and components, which play different roles and responses depending on the context. Therefore, it is necessary to understand this diversity of smart cities and to reflect the multi-contextuality in smart city model.

For adaptability – a smart city is constructed by multiple components and services that are interconnected or interacted. When one device in a smart city changes, this change will affect the devices and systems associated with it, and these interconnected devices or systems that need to react to this change and adapt to it. There is limited description of how these changes will affect other parts of the model. Although (Li et al., 2013) describes the characteristics required to become a smart resilient city, it does not specify how smart city services will be defined and responded to changes.

3 EVALUATION RESULTS

In the previous section, we divided smart city models into conceptual and structural groups, based on their characteristics. We also discussed the character of each group. From these studies, we have created the following table (Table 1), which shows how each model meets the characteristics we have defined. We have considered 4 evaluation criteria, which are service structure, interoperability, multi-context and adaptability.

- **Service Structure (S)** - Is the paper suggesting the view of services' structure? Is there any insight on how to design or analyze the structure of services?
- **Interoperability (I)** - Does the paper illustrate interoperability of the services or does it present the service as isolated with none or a very low level of interactions?
- **Multi-context (MC)** - Does the paper follow the idea of smart city as a multi-contextual environment? Are the authors familiar with the multi-contextual perspective, and do they reflect and consider the relations among the different contexts?
- **Adaptability (A)** - Does the paper count with the process of adaptation of the presented model? Are the authors discussing the changes of the model, depending on outer or inner impulses?

Smart city covers a wide range of stakeholders, advanced technologies and devices. We need to pay attention to this diversity of smart cities in order to achieve sustainable development of smart cities, and we have identified a few key features needed to ensure this diversity, and we aim to evaluate if those key features are met by the existing smart city models. Based on the results of the above smart city models review, the evaluation based on each feature will be discussed in the next sections.

3.1 Service Structure

As indicated in (Stepánek and Ge, 2018), the key features that are used to determine the structure of services are the interconnections of intelligent systems and smart service designs. We have divided all the selected models into two main groups: Conceptual and Structural, which depends on the characteristics of the models. In terms of the "structure" key feature, the structural group model provided more smart city services at the structural level, which was convenient with this key feature. Most of the models in the structural group showed smart services in general, while models 7 and 9 showed the structure of services more clearly. Although models 7 and 9 show the structure of smart city services, the relationship between them has not been clearly defined.

3.2 Interoperability

This key feature is one of the important factors to help understand the structure of smart city services,

Table 1: Evaluation Results of Smart City Models.

	Group	Literature name / model	S	I	MC	A
1	Conceptual	Conceptualizing smart city with Dimensions of Technology, People, and Institutions (Nam and Pardo, 2011)	N	N	N	N
2	Conceptual	Improving Smart City Design: A Conceptual Model for Governing Complex smart city Ecosystems (Hämäläinen and Tyrväinen, 2018)	N	N	N	N
3	Conceptual	Smart City Implementation and Discourses: An Integrated Conceptual Model. The case of Vienna (Fernandez-Anez et al., 2018)	N	P	N	N
4	Conceptual	Towards Smart and Resilient City: A Conceptual Model (Arafah et al., 2018)	N	N	N	N
5	Structural	The Smart City Ecosystem Framework – A Model for Planning smart cities (Chan and Paramel, 2018)	F	N	N	N
6	Structural	Defining Smart City Architecture for sustainability (Anthopoulos, 2015)	F	N	N	N
7	Structural	Smart City based on Digital Twins (Deren et al., 2021)	F	N	N	N
8	Structural	Geomatics for smart cities - Concept, Key Techniques, and Applications (Li et al., 2013)	F	P	N	N
9	Structural	smart city Layered Model (Walletzký et al., 2018)	F	P	N	N

Legend: "F" - Fulfilled; "P" - Partially; "N" - Not Fulfilled

such as the interactions between smart city services, how they work together, and what impact they have. From the above smart city models, models 8 and 9 show interoperability and can see how the design of smart city model's layers and their services are connected to each other. Although these models show interoperability between layers, they do not show interoperability of services on a single layer. By defining the services at that layer, it is possible to understand the structure of smart city services, how services are interconnected as well as their interrelationships. We found that understanding their interoperability can significantly impact the organization of smart city services and optimize the structure of smart city services.

3.3 Multi-contextuality

Smart city includes different stakeholders such as organizations, governments, individuals, and industry professionals, and their perspectives vary depending on their work experience, skills, and work environment. Smart city services also play different roles, which depend on the specifics of each sector, environmental impact factors, stakeholders, and contexts.

Smart city governments and experts need to take into account the diversity of smart cities when creating a smart city. Therefore, the smart city service model also needs to be developed by taking into account the versatility and multi-contextuality. The models are based on general and specific perspectives (IoT, data twin, ICT, etc.). Thus, it can be seen that it is necessary to develop a multi-contextual model.

3.4 Adaptability

It is critical that smart city models are organized in a way that is adaptable and responsive for service changes. Smart city services are interconnected and affecting each other mutually. If the changes in one part of a service can affect another part, it is important to consider this effect when designing a smart city service. The models we have chosen rarely take this point into account. Thus, it is valuable to develop a flexible model that can adapt to service change.

4 CONCLUSION

In this paper, we have searched literature on smart cities models. The research results have been refined to nine smart city models. In order to organize the models, we have classified the models into conceptual and structural groups. The conceptual models have focused on the smart city framework and interactions among various conceptual components, whereas the structural models are mostly layer-based and focused on different processes for smart cites. Based on the classification, we have further discussed the features of each model group. In order to further understand the models, we have evaluated the models based on their service structure, interoperability, multi-contextuality and adaptability. The evaluation results have shown how the smart cities models can be improved and work collaboratively. Also, the results also indicate how to build smart city models in the future.

As future work, we first plan to further develop the evaluation criteria into quantitative form, so that the models can be automatically evaluated. Also, we plan to include more smart city models and architectures into the evaluation to observe the similarity and differences among the models. This can be done by creating an alignment of the smart city models with a reference model.

REFERENCES

Anthopoulos, L. (2015). Defining smart city architecture for sustainability.

Anthopoulos, L., Janssen, M., and Weerakkody, V. (2019). *A Unified Smart City Model (USCM) for Smart City Conceptualization and Benchmarking*, pages 247–264.

Anthopoulos, L., Reddick, C., and Sirakoulis, K. (2021). Conceptualizing smart government: Interrelations and reciprocities with smart city. *Digital Government: Research and Practice*.

Arafah, Y., Winarso, H., and Suroso, D. S. A. (2018). Towards smart and resilient city: A conceptual model. *IOP Conference Series: Earth and Environmental Science*, 158:012045.

Bangui, H., Ge, M., and Buhnova, B. (2018). Exploring big data clustering algorithms for internet of things applications. In Muñoz, V. M., Wills, G. B., Walters, R. J., Firouzi, F., and Chang, V., editors, *Proceedings of the 3rd International Conference on Internet of Things, Big Data and Security, IoTBDS 2018, Funchal, Madeira, Portugal, March 19-21, 2018*, pages 269–276. SciTePress.

Bastidas, V., Reychav, I., Ofir, A., Bezbradica, M., and Helfert, M. (2021). Concepts for modeling smart cities. *Business & Information Systems Engineering*, pages 1–15.

Buhnova, B., Kazickova, T., Ge, M., Walletzký, L., Caputo, F., and Carrubbo, L. (2022). A cross-domain landscape of ICT services in smart cities. In Pardalos, P. M., Rassia, S. T., and Tsokas, A., editors, *Artificial Intelligence, Machine Learning, and Optimization Tools for Smart Cities: Designing for Sustainability*, Springer Optimization and Its Applications, pages 63–95. Springer.

Chan, B. and Paramel, R. (2018). The smart city ecosystem framework – a model for planning smart cities.

Chourabi, H., Nam, T., Walker, S., Gil-Garcia, J. R., Mellouli, S., Nahon, K., Pardo, T., and Scholl, H. (2012). Understanding smart cities: An integrative framework. *45th Hawaii International Conference on System Sciences*, pages 2289–2297.

Deren, L., Wenbo, Y., and Shao, Z. (2021). Smart city based on digital twins. *Computational Urban Science*, 1:4.

Desouza, K. and Flanery, T. (2013). Designing, planning, and managing resilient cities: A conceptual framework. *Cities*, 35:89–99.

Dragoicea, M., Walletzký, L., Carrubbo, L., Badr, N. G., Toli, A. M., Romanovská, F., and Ge, M. (2020). Service design for resilience: A multi-contextual modeling perspective. *IEEE Access*, 8:185526–185543.

Fernandez-Anez, V., Fernández-Güell, J. M., and Giffinger, R. (2018). Smart city implementation and discourses: An integrated conceptual model. the case of vienna. *Cities*, 78:4–16.

Ge, M., Chren, S., Rossi, B., and Pitner, T. (2019). Data quality management framework for smart grid systems. In Abramowicz, W. and Corchuelo, R., editors, *Business Information Systems - 22nd International Conference, BIS 2019, Seville, Spain, June 26-28, 2019, Proceedings, Part II*, volume 354 of *Lecture Notes in Business Information Processing*, pages 299–310. Springer.

Hämäläinen, M. and Tyrväinen, P. (2018). Improving smart city design: A conceptual model for governing complex smart city ecosystems. pages 265–277.

Lee, J., Hancock, M., and Hu, M.-C. (2014). Towards an effective framework for building smart cities: Lessons from seoul and san francisco. *Technological Forecasting and Social Change*, 89:80–99.

Li, D., Shan, J., Shao, Z., Zhou, X., and Yao, Y. (2013). Geomatics for smart cities - concept, key techniques, and applications. *Geo-spatial Information Science*, 16:13–24.

Liu, Q., Ullah, H., Wan, W., Peng, Z., Hou, L., Sanam, S., Rizvi, D. S., Ali Haidery, S., Qu, T., and Muzahid, A. (2020). Categorization of green spaces for a sustainable environment and smart city architecture by utilizing big data. *Electronics*, 9.

Lom, M. and Přibyl, O. (2020). Smart city model based on systems theory. *International Journal of Information Management*, 56:102092.

Mbarek, B., Ge, M., and Pitner, T. (2021). Trust-based authentication for smart home systems. *Wirel. Pers. Commun.*, 117(3):2157–2172.

Nam, T. and Pardo, T. (2011). Conceptualizing smart city with dimensions of technology, people, and institutions. pages 282–291.

Neirotti, P., De Marco, A., Cagliano, A. C., Mangano, G., and Scorrano, F. (2014). Current trends in smart city initiatives: Some stylised facts. *Cities*, 38:25–36.

Piro, G., Cianci, I., Grieco, L., Boggia, G., and Camarda, P. (2013). Information centric services in smart cities. *Journal of Systems and Software*, 88.

Stepánek, P. and Ge, M. (2018). Validation and extension of the smart city ontology. In *Proceedings of the 20th International Conference on Enterprise Information Systems, ICEIS 2018, Funchal, Madeira, Portugal, March 21-24, 2018, Volume 2*, pages 406–413. SciTePress.

Stepánek, P., Ge, M., and Walletzký, L. (2017). It-enabled digital service design principles - lessons learned from digital cities. In Themistocleous, M. and Morabito, V., editors, *Information Systems - 14th European, Mediterranean, and Middle Eastern Conference, EMCIS 2017, Coimbra, Portugal, September 7-8, 2017,* *Proceedings*, volume 299 of *Lecture Notes in Business Information Processing*, pages 186–196. Springer.

Trang, L. H., Bangui, H., Ge, M., and Buhnova, B. (2019). Scaling big data applications in smart city with coresets. In Hammoudi, S., Quix, C., and Bernardino, J., editors, *Proceedings of the 8th International Conference on Data Science, Technology and Applications, DATA 2019, Prague, Czech Republic, July 26-28, 2019*, pages 357–363. SciTePress.

Walletzký, L., Buhnova, B., and Carrubbo, L. (2018). *Value-Driven Conceptualization of Services in the Smart City: A Layered Approach*, pages 85–98.

Walletzký, L., Carrubbo, L., and Ge, M. (2019). Modelling service design and complexity for multi-contextual applications in smart cities. In *23rd International Conference on System Theory, Control and Computing, ICSTCC 2019, Sinaia, Romania, October 9-11, 2019*, pages 101–106. IEEE.

Walletzký, L., Romanovská, F., Toli, A. M., and Ge, M. (2020). Research challenges of open data as a service for smart cities. In Ferguson, D., Helfert, M., and Pahl, C., editors, *Proceedings of the 10th International Conference on Cloud Computing and Services Science, CLOSER 2020, Prague, Czech Republic, May 7-9, 2020*, pages 468–472. SCITEPRESS.

Wey, W.-M. and Hsu, J. (2014). New urbanism and smart growth: Toward achieving a smart national taipei university district. *Habitat International*, 42:164–174.

Yang, Q., Ge, M., and Helfert, M. (2019). Analysis of data warehouse architectures: Modeling and classification. In Filipe, J., Smialek, M., Brodsky, A., and Hammoudi, S., editors, *Proceedings of the 21st International Conference on Enterprise Information Systems, ICEIS 2019, Heraklion, Crete, Greece, May 3-5, 2019, Volume 2*, pages 604–611. SciTePress.