Unified Smart City Domain Model for Central Europe

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Abstract. In recent years, the concept and implementation of smart cities has become an important topic at the level of countries, regions and cities. However, it is currently not clearly defined what all areas are part of a smart city, or what functional domains a smart city addresses. The aim of this paper is to analyse the current state of smart city concepts in the world and then to identify the functional domains that define the areas belonging to a smart city. This analysis represents an input to propose a further model of functional domains for Central Europe. The relevance of the model is verified by comparing the identified functional domains with existing regional and national smart city strategies in the Czech Republic.

Keywords: Smart city model · smart energy · smart infrastructure · smart transportation · smart healthcare · analysis · functional domains · cybersecurity

1 Introduction

Over more than the last decade, the smart city label has spread across the globe, influencing city strategies regardless of their size. The concept of smart city has also been introduced as a strategy [1] encompassing modern urban environments with an emphasis on the effective use of modern information and communication technologies (ICT) especially to enhance their competitiveness [2]. In order to face the growing problems related with the urban areas development, which are analyzed in detail [3], and their agglomerations, responsible governmental units, local businesses, non-profit organizations and other actors must make a concerted and managed effort to solve these problems [4].

In order to effectively solve the problems associated with the implementation of smart cities, it is essential to involve the target group itself, i.e. the citizens living in these cities and their social activities in the form of non-profit organizations, etc., so that the idea of smart cities associated with the implementation of modern intelligent ICT systems as it is presented in their articles [5, 6]. The smart city idea itself is not new, but the first references can be found as early as 1993 [7], where various investments in

P. Cong Vinh and H. Mahfooz Ul Haque (Eds.): ICTCC 2023, LNICST 586, pp. 98–110, 2024.
https://doi.org/10.1007/978-3-031-59462-5_7

telecommunications in Singapore are documented and represent the role they have in the production and distribution processes that define Singapore [7] as a "smart city".

It is therefore clear that the smart city issue has been addressed for many years and that selected parts of the smart city concept have been implemented in various ways. However, it is necessary to answer together with the authors of the article smart city and Value Creation [8] the question of what all smart city is, or what functional domains the smart city area includes, as we can agree with the authors that there is no recognized definition of a smart city so far and some cities that call themselves smart are completely lacking a strategic vision of their smart future. The question is how to approach this issue holistically and identify the different functional domains of a smart city. In order to identify the functional domains that are part of a smart city, the decision has been made to construct a unified and all-encompassing model by analyzing the findings derived from previously conducted reviews.

The first step to find a coherent and unified model of functional domains is to analyze the conclusions of the already developed reviews. The second step is to verify the degree of applicability of the proposed model in current smart city strategies in the Czech Republic and to generalize this model for use in Central Europe.

2 Related Work

2.1 Functional Smart City Domains

The search for a definition of the meaning of a smart city is addressed in the Systematic Literature Review [10], with an emphasis on the search for an answer whether smart City is included in specific urban strategies promoted by government strategies or whether they face specific urban problems without a comprehensive framework. What all can be included in smart city strategies remains unclear and often vague which is also based on the analysis published in the article Smart Cities: Definitions, Dimensions, Performance, and Initiatives [11], which aims to clarify the meaning of the word "smart" in the context of cities through an approach based on an in-depth review of relevant studies as well as official documents of international institutions.

A new perspective based on defining smart city domains of interest is then provided by the Literature Review [12], based on a literature review, with the aim of discovering and classifying the different schools of thought, universities and research centres as well as companies that deal with the smart city domain, and discovering alternative, models, architectures, approaches and frameworks.

A similar approach is presented in [13], which analyses more than a hundred sources with a focus on providing a data-driven view of smart city architectures and the key technologies that enable their implementation. However, despite the dozens of published papers on smart city, there is no major shift in finding a coherent smart city model, which is also the case of Camero A. and Alba E. [14], who in 2019 mapped in detail the targeted use of modern ICT technologies in the smart grid. Despite the non-perfection or even the absence of a single comprehensive smart city model, there are a number of sub-project implementations around the world, where the challenges arising from the interdependence of the different smart city domains have to be addressed, involving significant political, technical and socio-economic challenges for the designers, integrators

and organisations involved in the management of these new entities. This is the area addressed in the study [15], which focuses on security, privacy and risk in smart cities, highlighting information security threats and challenges to smart city infrastructure in the area of data management and processing. The study analyses many of these challenges, offers a synthesis of relevant key literature and develops a framework for smart city interaction.

2.2 Architecture Models

The approach of Lombardi, et al. [18] focused on generic models and architectures that describe the main smart city characteristics, and also approaches which can result to improve its smartness. Primarily, this involves defining and quantifying strategic visions for cities. A different approach is then presented by Dameri [19], who uses the following basic components to define a smart city: people, land, infrastructure and government (Fig. 1).

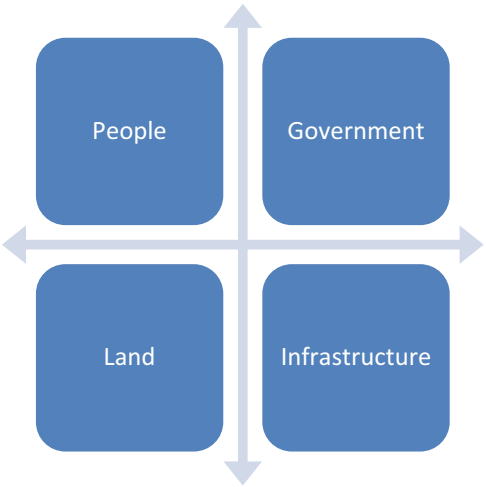

Fig. 1. The core city components [19]

Land is the geographical area in which a city is located. Infrastructure includes transport facilities, etc. People includes all citizens, not just residents. Government includes the city authorities whose task is to manage the administration of the city. From a smart city perspective, according to [20, 21], it is necessary to include the main aspects of a smart city, which are efficiency, environmental friendliness and innovation.

The general goal of smart cities is to improve the quality of everyday life of citizens, who are often unaware that the city or government is designing, implementing and operating smart solutions, as they are not involved in defining smart city priorities and projects on the quality of life [22]. Thus, cities create strategies and visions, but their outputs are not sufficiently communicated to citizens. Palumbo and Cosseta underscore the pivotal role of individuals in the concept of a smart city [22]. In their

focus on social innovation, they assert that social and open innovation are crucial for generating fresh ideas associated with smart cities. Another intriguing perspective on generating public value in a smart city is outlined by [23] in their conceptual model. In this context, the author highlights that creating value and ensuring citizen benefits in a smart city necessitate active participation in research activities, the implementation of policy commitments, citizen engagement, and financial support from the private sector for individual smart city initiatives, along with the provision of tangible technical solutions. It is indisputable, therefore, that the overarching objective of smart cities is to enhance both the overall quality of the city and the quality of life within it. While these two aspects are not synonymous, they are intricately interconnected, primarily through specific smart projects [24, 25].

The intelligence of a city itself encompasses various dimensions. Giffinger [26], a highly cited author, identifies six distinct dimensions of a smart city, as illustrated in Fig. 2. Employing this framework to categorize specific smart projects and construct an evaluation framework poses challenges, particularly due to the interrelated or overlapping nature of these different dimensions.

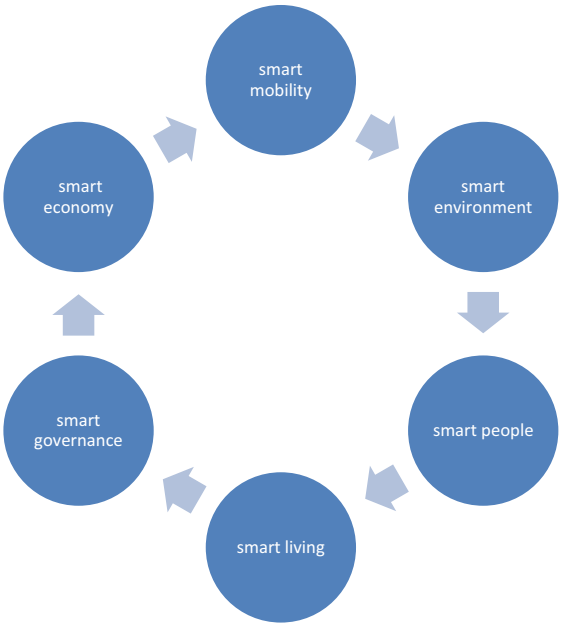

Fig. 2. The dimensions of a smart city [26].

Hence, employing a framework proves to be a more effective approach, grounded in the fundamental smart city components, comprising a diverse range of projects aimed at enhancing either the city's quality of life or the city itself. This enhancement is gauged through a set of KPI', reflective of the distinct benefits emanating from each project. Consequently, articulating and quantifying the manifold advantages brought about by an individual project is a more streamlined approach [27].

Individual projects serve as instrumental tools for the implementation of a smart city. These projects ought to possess specific attributes, particularly leveraging advanced technological solutions, aligning with both environmental and economic considerations. A multitude of smart projects often concentrate on specific domains such as energy efficiency in buildings, greenhouse gas emission reduction, widespread broadband adoption, delivery of e-services, mobile government, and more. However, it becomes increasingly crucial not only to furnish technical solutions to urban challenges but also to integrate each project into a comprehensive overarching smart framework [28].

2.3 Smart City Strategies Around the World

Agenda 21 serves as the foundational document outlining a development plan for the 21st century, impacting not only individual countries but the entire world. Also, it plays a substantial role in shaping the contemporary manifestation of the smart city perspective in the Czech Republic. [29]. It was approved at the United Nations (UN) Conference on Environment and Development in Rio de Janeiro in 1992 and is considered one of the basic long-term strategic plans for sustainable development, which is applicable both at the global level and at the level of individual countries and administrative regions. Particularly relevant for the implementation of the plan in individual territories is Chapter 28: Local Government Initiatives to Promote Agenda 21, in the section on Empowering Important and Relevant Groups, which calls on the relevant public authorities in each territory to adopt the plan as their own agenda [30]. Consequently, the Czech Republic initiated a development program named MA21 [31], overseen directly by the Ministry of the Environment. MA21 functions as a practical tool, translating the tenets of sustainable development into actionable measures tailored for municipalities and regions. Its purpose is to guarantee a high and good well-being and ecological conditions in a designated area.

In direct continuity with Agenda 21, other global plans have been developed. Among these, the pivotal document is the Millennium Declaration [32], primarily centered around 8 Millennium Development Goals. Subsequent to the Millennium Declaration, the present UN worldwide initiative is the Agenda 2030 [33], outlining 17 Sustainable Development Goals, spanning the years 2015 to 2030.

This principle extends to documents dedicated to supporting the smart city endeavor, aligning seamlessly with the SDGs. The inception of this initiative within the EU traces back to Europe 2020 or the Digital Agenda—a decade-long strategy geared towards fostering intelligent and sustainable development. Stemming from this framework, a sector-specific initiative named Smart Cities and Communities was inaugurated in 2011, concentrating primarily on industrial aspects. In 2012, The European Innovation Partnership on Smart Cities and Communities was established, imparting a foundational structure to the Smart Cities concept (Smart Cities Methodology, 2018).

2.4 Smart City Strategies in the Czech Republic

The Czech Republic has pledged to fulfill the objectives outlined in the 2030 Agenda, leading to the establishment of the Strategic Framework Czech Republic 2030 [34]. This document, emerging as a result of this commitment, serves as the cornerstone for the

smart city initiative in the Czech Republic. Issued by the Office of the Government of the Czech Republic, it stands as a comprehensive strategic development framework upon which various sub-national and regional documents/strategies derive their foundation. It is the basis for the Regional Development Strategy 2021+ [35], which, based on the above-mentioned framework document, sets out the objectives at the national level for the period of years 2021–2027 (seven years). The SRR21+ explicitly outlines its primary objective as pinpointing a tailored approach aligned with the need of individual regions. It aims to identify specific interventions to foster a balance in competitiveness among regions while concurrently fostering sustainable development within each specific region.

The Innovation Strategy of the Czech Republic for the period 2019–2023 [36] stands out as another pivotal document. It serves as a strategic blueprint for the Czech Republic's approach to research, development, and innovations, aspiring to position the country among the most innovative within the EU. Within this framework, the strategy also unveiled a fresh brand: "Cech Republic: The country for the future", being presented at the international level.

In accordance with the Smart Cities Concept and under the influence of all the above-mentioned documents, at the turn of 2020–2021 new development and Smart Strategies started to emerge in individual regions of the Czech Republic with a view to the following years, most often to 2027. However, there is currently no analysis that confirms that the respective regional strategies contain functional domains that are truly relevant for the smart city area.

3 Identification and Analysis of Functional Domains

3.1 Processing Methods

In the description of the current state of the problem, mainly general scientific methods were used. First of all, a search of available materials was used, especially documents in electronic form, norms, laws, standards and articles from the Internet. The literature search helped to provide an up-to-date view of the issue under study. Among the general methods, analysis, synthesis, comparison, induction and deduction were also used. Analysis was used in the context of objectifying and clarifying the various aspects and relationships under study within the Smart Cities concept. Synthesis was used to summarize the findings. Comparison was used mainly in the context of comparing the different aspects under investigation. In-duction and deduction was used to establish the relationships between the different aspects. The collected documents underwent categorization based on the entity responsible for their publication: public institution, university, or private company. Their content underwent additional scrutiny employing the methods, as well as through the lens of Nam and Pardo's smart city model [16] (see Fig. 3). This model was selected for analysis as it delineates a smart city framework across three dimensions: technology, institutions, and people.

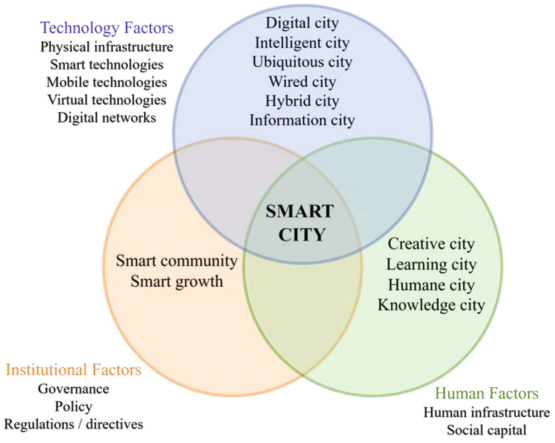

Fig. 3. Smart city core components [16]

The following outlines the steps in the conducted analysis of the current state of the art solutions for addressing smart city challenges. This analysis aimed to identify the functional domains of the smart city model withing the broader context of the scientific community and the overarching concept of a smart city. For the systematic analysis, the PRISMA approach [17] was used, the specific use of which is illustrated in the process diagram Fig. 4.

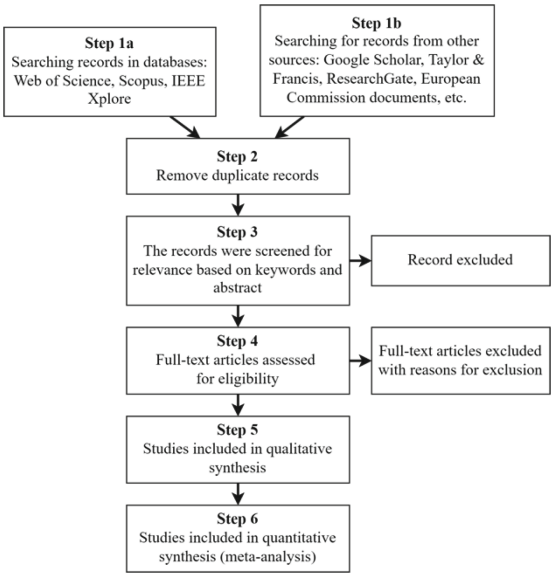

Fig. 4. System Analysis Process

3.2 Input Data

The input data were articles indexed in the Web of Science, Scopus and IEEE Xplore databases, supplemented by articles from Google scholar, Taylor & Francis, Rasearch-Gate and documents published by the European Commission and national smart city strategies. At the same time, the time criterion was chosen that the articles were no older than five years, i.e. from 2017 to 2022. The following keywords were used for the analysis, linked to the search strings:

- smart city &
  - o energy; smart energy; smart grid smart city; smart building; smart street; smart lightning; energy management; smart streetlight; IoT smart city; 5G smart city; smart governance; e-government; smart city governance; e-governance; smart government; collaborative governance; internet of things; social networks; machine learning; air pollution; internet of health things; unmanned aerial vehicles; smart government; smart waste management; disabled people; fire fighters; unmanned aerial vehicles; police; communication; e-health; education; smart education; Innovation; smart city education; smart people; knowledge economy; smart urbanism; smart citizenship; entrepreneurship, citizen education; research; schools; science; start-ups; security; air quality; water meter; electricity meter; culture; tourism; image detection; Image processing; outdoor parking; parking detection; smart cities; traffic engineering; improving; parking; availability; prediction.

3.3 Analysis Results

The analysis was divided into sub-phases. In the first phase, 307 articles were selected on the basis of the above criteria, which were then selected, and duplicates were removed in the second phase. This resulted in 268 articles that were referred for further analysis. In the third phase, abstract analysis was performed to eliminate selection bias based on the search strings from the above keywords.

After this analysis, 54 articles were excluded. This relatively high number can be attributed to the extensive combination of keywords. Thus, a total of 214 articles were subjected to the fourth stage. In this phase, a full text analysis was conducted to analyze and thematically categorize the articles into groups to define the resulting functional domains of the smart city model from a quantitative perspective, while simultaneously implementing a qualitative view of the articles with an emphasis on their contribution and innovativeness. This phase of analysis resulted in 159 detailed ana-lysed articles that were used to create the smart city functional domain model.

The examination of the articles led to the recognition of five vertical functional domains that represents the fundamental areas of interest in the context of a smart city. These are Transportation and accessibility, Technical infrastructure, Healthcare and Social services, Public administration and Environment, Tourism, Culture. These are supplemented by two overarching horizontal domains, specifically Education, identified as pivotal through the analysis and Cybersecurity. Both domains strongly support and influence the design in all other domains. It can be deduced that these domains are crucial for all forthcoming implementations and, as such, should be accorded special attention (Fig. 5).

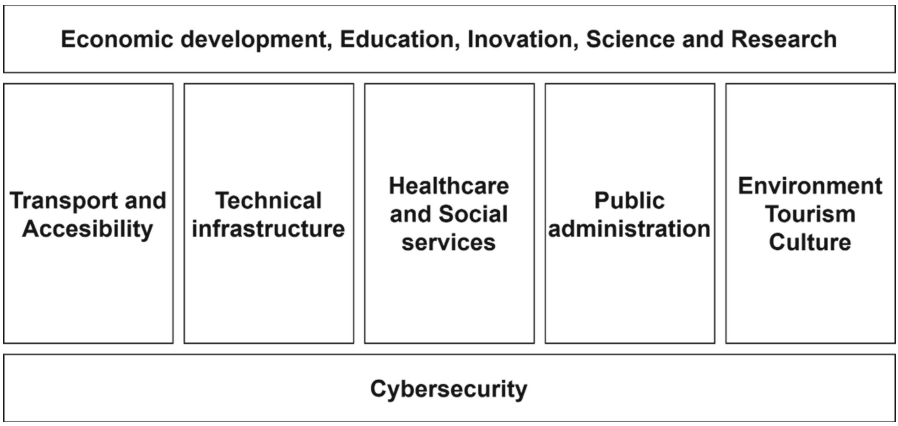

Fig. 5. Smart city application domains

Furthermore, an analysis was conducted to determine whether individual regions actively engage in the implementation of the SMART concept within their territories, and if this concept is integrated into their respective development strategies for the current period (Table 1).

Table 1. Regions and abbreviations

Region name	Abbreviation	Region name	Abbreviation
Central Bohemia Region	CB	Pardubice Region	PA
South Bohemia Region	SB	Vysočina Region	VY
Ústí Region	ÚS	South Moravia Region	SM
Karlovy Vary Region	KV	Olomouc Region	OL
Liberec Region	LB	Moravia-Silesia Region	MS
Hradec Králové Region	HK	Zlín Region	ZL
Capital City of Prague	PR	Plzeň Region	PL

The proposed model is retrospectively evaluated by comparing it with the strategies of individual regions to assess its relevance (Table 2).

Seven of the fourteen regions analysed have developed a separate strategy oriented towards the implementation of the Smart concept. The opposite is true for the Plzeň Region, where the latest version of the regional strategy is 2014 +, which is also reflected in the results in the table above.

The number of priority areas (PAs) in the documents ranges from four (specifically the Pardubice Region), to ten (the Central Bohemian Region), with six and seven PAs having the largest representation. From the nomenclature and the articulation of specific domains in the certain regions, the impact of the Czech Smart Cities Concept is evident. These regions have augmented the concept with elements that are characteristic

Table 2. Application domains in region strategies. (✓ included ✕ Not included ~ Partly included)

/ Regions Domains	CB	SB	ÚS	KV	LB	HK	PR	PA	VY	SM	OL	MS	ZL	PL
Economic development, Education, Innovation, Science and Research	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✕
Transportation and accessibility	✓	✓	~	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✕
Technical infrastructure	✓	✓	✓	✓	✓	✓	✓	✓	✓	~	✓	✓	✓	✕
Healthcare and social services	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Public administration	~	~	~	✓	✓	✓	✓	✓	✓	✓	✓	~	✓	✕
Environment, Tourism, Culture	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✕
Cybersecurity	✕	✕	✕	✓	✕	✕	~	✕	✕	✕	✕	✕	✓	✕

and unique to them, such as the inclusion of spa-related considerations in the Karlovy Vary Region. In contrast, some regions adhered to the conventional smart city domains outlined in the study "Mapping Smart Cities in the EU" [40], published by the European Parliament. Drawing from a similar analysis across the European cities, this study defined six fundamental smart city domains: (1) Smart Governance, (2) Smart Economy, (3) Smart Mobility, (4) Smart Environment, (5) Smart People and (6) Smart Living. The structure of Priority Areas (PAs) in the strategies of the Zlín and Liberec regions closely aligns with this conceptual framework. While other regions have taken diverse approaches in formulating their PAs, they still address all key thematic areas, albeit sometimes in the form of specific objectives. Notably, education, science, research, and innovation were consistently represented in all regional strategies, reflecting the influence of the previously mentioned Innovation Strategy, particularly the RIS3 strategy, which places a specific focus on these areas. The individual regions adapt this strategy in their own regional innovation strategies to meet their specific requirements. This underscores the significance of this domain and reinforces the assertion in the Innovation Strategy that education, science, research, and innovation play a pivotal role in realizing all 17 Sustainable Development Goals (SDGs).

4 Conclusion

The issue of smart city has been addressed for many years, and selected parts of the smart city concept have been implemented in various ways. Based on a detailed analysis of relevant scientific articles, a total of seven functional domains have been identified, which represent key areas for the fulfilment of the added value of the implementation of the smart city concept and its applicability for the improvement of the life of inhabitants and the design of a functional model of the smart city. The relevance of the model was further verified in detail in the individual smart city strategies in the Czech Republic, confirming the relevance of these domains and their solutions in the current smart city strategies in the Czech Republic. Approaches to smart city implementation within the Central European countries also largely reflect the identified functional domains. The proposed model is therefore fully applicable also in Central European countries. A current key topic in the smart city area that needs to be addressed in further research is the area of cyber security. Cybersecurity brings key requirements for ensuring security within all other functional domains of the proposed model, but is currently not sufficiently addressed in smart city strategies. Based on the adopted Directive (EU) 2022/2555 of the European Parliament and of the Council of 14 December 2022 on measures for a high common level of cybersecurity across the Union, amending Regulation (EU) No 910/2014 and Directive (EU) 2018/1972, and repealing Directive (EU) 2016/1148 (NIS 2 Directive), it can be expected that local governments will be designated as obliged entities under this Directive and thus will have to ensure the implementation of information and cybersecurity requirements also within the smart city framework. Therefore, the identification of vulnerabilities in smart city systems and the process of addressing them, including ensuring compliance with NIS2, becomes a key focus for further research in this area.

Acknowledgement. The financial support of the project "Application of Artificial Intelligence for Ensuring Cyber Security in Smart City", No.VJ02010016, granted by the Ministry of the Interior of the Czech Republic is gratefully acknowledged.

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