Design of Smart Cities Dimensions Using the SmartCitySysML Profile

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Abstract. Dimensions of smart cities are identified and described from essential factors and characteristics to improve efficiency, sustainability, and quality of life for the citizens living in these cities. It is possible to note in the literature that the domains areas are not yet consolidated for structuring the dimensions of a smart city. In this article, the main idea is to describe the extension of a SysML profile to model dimensions of smart cities as native elements of system design. The profile extension, named SmartCitySysML, has been extended from SysML Internal Block Definition diagrams. The conception of this extension arose from the need to think about different dimensions to separate interests and to improve the focus on problem-solving. As a result, the SmartCitySysML profile facilitates the use of common elements of smart cities and provides a visual representation to evaluate the quality of diagrams from a practical point of view, as it provides using common terminology well-known by the stakeholders that are responsible for managing a variety of aspects of a smart city.

Keywords: SysML · Smart Cities · Dimensions

1 Introduction

Modern life in cities is highly dependent on infrastructures such as roads, energy, water, and waste supply. These infrastructures are in high demand by citizens and organizations, and their design and maintenance are crucial to our daily activities. Cities infrastructures' receive data and retrieve information, and consequently present high complexity and demand, which leads to the need to apply Information and Communication Technologies and Processes for their design, control, and management.

The term smart city generally refers to the search and identification of smart solutions that allow modern cities to improve the quality of services provided to citizens through creativity, innovation, and decision-making in a fast and efficient way [11]. A smart city has a good prospective performance in the economy, improves governance and mobility, and provides better daily life for citizens [15]. According to Nilssen [23], smart cities are considered as representations of holistic ideas and sustainable development, considering the focus on technology,

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human resources, and collaborative governance, or the combination of the three as a defining resource.

Adapting and evolving a city to new processes and applications is a strategy adopted to mitigate the problems generated by urban population growth and rapid urbanization, e.g., air pollution, resource scarcity, waste management, inadequate infrastructure due to deterioration, health concerns, and traffic congestion [7].

Currently, many modeling languages are used for modeling software systems that are responsible for the control of city infrastructures'. SysML [24], for example, is a UML profile applied to systems that include hardware, software, information, processes, people, and procedures. SysML has gained attention in recent years [29–31,33,35] as it also models elements of systems that are not software.

This article proposes to identify several areas, separate interests, represent elements focused on the dimensions of a smart city, and improve the focus on problem-solving by adapting an existing SmartCitySysML profile, improved in this article.

Dimensions proposed in the SmartCitySysML profile have been identified and described from essential factors for a smart city to improve efficiency, sustainability, and quality of life for the citizens of these cities. For the dimensions of the SmartCitySysML profile, the SysML Internal Block diagram is extended to describe the internal structure of a block in terms of properties and connectors between properties. A block can include elements, properties, values, parts, and references to other blocks. In the SmartCitySysML profile, the SysML Internal Block diagram is used to describe the main dimensions of a smart city.

2 Background

This section presents a brief overview of the concepts of Smart Cities and SysML.

2.1 Smart Cities

A smart city is a safe, efficient, and environmentally friendly urban center with infrastructure designed, built, and maintained through technology [36]. A smart city can be explained in terms of complex services and products designed to provide solutions to efficiently improve the management of modern cities. These solutions gather information from citizens about their activities, preferences, and habits [34,41]. Smart cities depend upon creative and knowledge resources to maximize their innovation potential.

Smart cities are portrayed as the association of several connected networks, that is, an integrated and multidimensional system that provides continuous data on the movements of people and materials in terms of the flow of decisions on the physical and social form of the city to face urban challenges [3,13]. Smart cities act as distributed systems to facilitate the analysis and interpretation of large-scale, real-time data, the creation of new urban services, and the deployment and optimization of infrastructures [25,27].

Urban challenges stimulated the search for better quality services, therefore, they encouraged cities to find a way to integrate technology in all aspects of the urban environment to offer better quality of life to citizens [4]. According to Albino et al. [1], there are four commonest characteristics of emerging smart cities. First, the network infrastructure of a city that permits political and social efficiency and cultural development. Second, a stress on urban development led by companies and inventive activities for promoting urban growth. Third, social inclusion of varied urban residents and social capital in urban development. Finally, the natural environment may be a strategic component for the longer term.

Cities, however, become smart when they make use of Information and Communication Technologies (ICT) to integrate and synthesize these data for some purpose, for example, ways to improve efficiency, equity, sustainability, and quality of life in cities [3]. A smart city is intended as an urban environment that, supported by pervasive ICT systems, can offer advanced and innovative services to citizens to improve the overall quality of their daily life [10,26].

2.2 Brief Introduction to SysML

SysML [24] has been developed by the Object Management Group (OMG) and International Council on Systems Engineering (INCOSE) to develop a unified language for general-purpose modeling for systems engineering applications. SysML is a UML profile applied to systems that include hardware, software, information, processes, people, and procedures. The SysML diagrams are [24]:

- Activity, Sequence, State Machine, and Use Cases diagrams to model behavior;
- Requirements diagram to model requirements;
- Block Definition, Internal Block, Parametric, and Package diagrams to model structure.

Sequence, State Machine, Use Cases, and Package diagrams have not been changed from UML 2.0, except that their focus is broader, regarding software as well as systems elements. Block Definition, Activity, and Internal Blocks diagrams have been modified from UML, and the Requirements and Parametric diagrams are new [24].

SysML reuses parts of UML and additionally offers new language elements, such as value types, type of quantity, and the opportunity to describe the functionality of systems. Therefore, it allows one to model a wide variety of systems from different perspectives [44]. Current version of SysML, named SysML 1.6, was released in December 2019 [24].

It is worth mentioning that SysML also allows modeling in multiple architectural views, through diagrams that can model the structure, behavior, and requirements of a system. In this way, SysML is characterized through diagrams, models, structural and behavioral elements, effective in specifying requirements, allocations, and restrictions on system properties to support a systems engineering project [5,14].

SysML limitations have been identified regarding formal modeling and mathematical analysis of models, thus limiting the ability to analyze and verify the specifications of systems [40,44].

3 Related Work

This section presents work related to the dimensions of a smart city for the elaboration of the extension of a SysML profile.

Giffinger et al. [15] declare that a smart city has six dimensions for urban development with awareness and participation of citizens of a city. These six dimensions, defined by Giffinger et al., are the smart economy, smart people, smart environment, smart governance, smart mobility, and smart living. Cohen [8], Moustaka et al. [19] and Staffans and Horelli [39] also declared the same dimensions, but with different factors and/or characteristics for smart cities.

Nam and Prado [22] present technology, people, and institutions as the main dimensions of an intelligent city. The technology dimension is composed of a digital city, intelligent city, ubiquitous city, wired city, hybrid city, and information city. The people dimension is composed of a creative city, a learning city, a human city, and a knowledge city. Finally, the institution's dimension is composed of a smart community.

Chourabi et al. [7] proposed a framework for smart city dimensions using a set of factors that affect the design, implementation, and usability of smart cities from smart initiatives, shared services, and challenges. These factors are management and organization, technology, governance, policy context, people and communities, economy, built infrastructure, and natural environment.

Reichwein et al. [28] present a high-level system architecture model defined in SysML and a dynamic system model defined in Modelica. The system components, as well as their interfaces, can be represented through the definition of SysML Block Definition and Internal Block diagrams.

Roche [32] represents an intelligent city, digital city, open city, and live city as the main dimensions of an intelligent city. The intelligent city dimension is composed of social infrastructure. The digital city dimensions are composed of an informational infrastructure. The open city dimension is composed of open governance. Finally, the live city dimension is composed of a continuously adaptive urban living fabric.

Barbieri et al. [2] proposed a SysML modeling architecture and design pattern to build models that enhance traceability of information, facilitating the analysis of change influences in later life cycle phases of the system and reuse for future projects.

Jucevičius et al. [17] introduced a model for the dimensions of smart cities based on the characteristics of smart agile, smart digital, smart learning, smart sustainable, smart knowledge-driven, smart network, and smart innovation.

Fagioli [12] states that a smart city must follow standards of quality of life and productivity from social assets, environment, economy, governance, mobility, and

housing. The author adds that the main problems of a sensible city are energy, pollution, and infrastructure.

Nilssen [23] elaborated a typology composed of four dimensions of smart cities (technological, organizational, collaborative, and experimental) focused on technological innovations, for example, new practices, products, and services focused on organizational and collaborative innovations.

4 SmartCitySysML Profile Dimensions

This section is an extension of the profile, named SmartCitySysML [38], proposed by the authors themselves and based on the dimensions of people, governance, environment, economy, and mobility. The development of a profile for smart cities arose from the challenges resulting from urban growth and the need to develop smart, transparent, and sustainable urban strategies, as well as the structuring and illustration of the characteristics and peculiarities of a city to make decisions quickly and efficiently.

A profile makes it easier to compose decisions based on better-described facts, encourages stakeholder involvement, promotes the exchange of experiences by analyzing the strengths and weaknesses of a city, engages in the needs of each dimension of a city, and uses smarter technologies and approaches to provide better services and quality of life for citizens.

Dimensions of a smart city are considered as part of the development to be pursued, to allow the equity of present and future generations equity in living conditions and have relevant factors that reflect the important aspects of each intelligent characteristic. These dimensions approximate the needs of the applications and the elements in the field of modeling applications in smart cities, both in design and software architecture, improve the monitoring of the city, as they gather information (incidents or emergencies) from all sources with easy and quick access, act dynamically on the needs of citizens, comprise useful services and information for better decision-making, and offer different types of innovation and initiatives [20,21,23].

The Dimensions of people, economy, mobility, governance, environment, and living are illustrated in Fig. 1 and identified in Cohen [8], Giffinger and Gudrun [15], Moustaka et al. [19], and Staffans and Horelli [39].

4.1 People

People, as depicted in Fig. 2, refers to social and human capital, social learning and education, the level of qualification of women and men from different backgrounds, motivation to learn and participate in the co-creation of public life, affinity to lifelong learning, social ethnic plurality, open-mindedness and individuals' participation in public life. Some values are equity, creativity, flexibility, cosmopolitanism, and tolerance [8,15,19,39].

For the people dimension, people's needs have to be identified, modeled, understood, and designed as solutions to provide education and training that

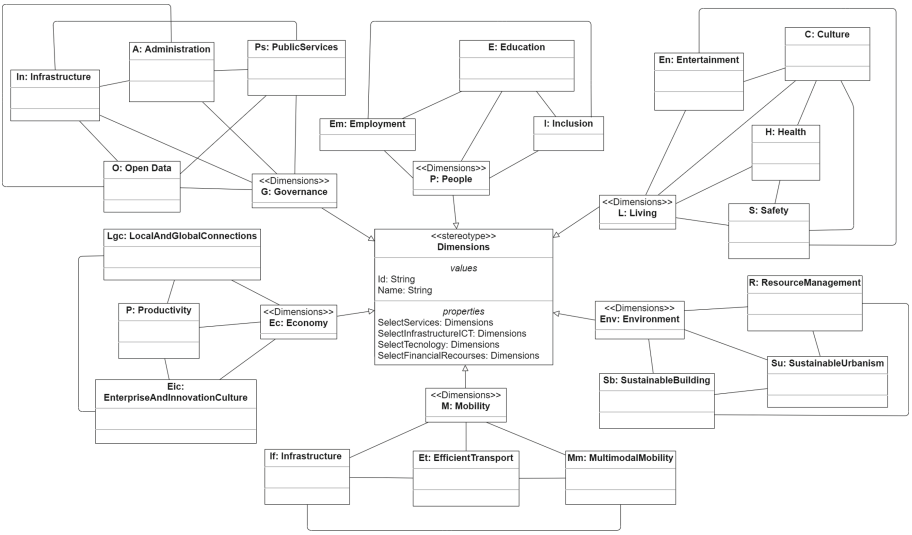


Fig. 1. SysML internal block diagram for the dimensions of interest in a Smart City.

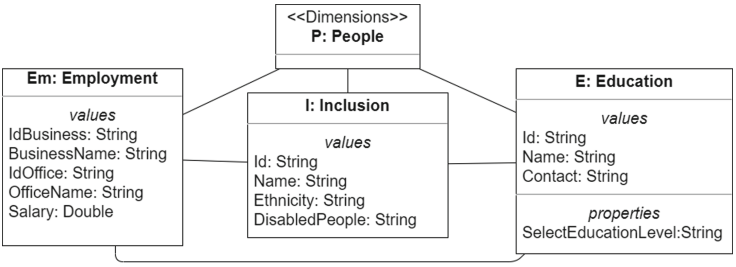


Fig. 2. SysML internal block diagram for the people dimension of a Smart City.

promote innovation and creativity [6]. Kumar and Dahiya [18] complement by stating that smart people are fundamental in a smart city. Smart people are open-minded, have a multicultural perspective, maintain a healthy lifestyle, and are actively involved in the sustainable and harmonious development of their cities. Therefore, without the active participation and involvement of smart people, a smart city will not be able to function.

4.2 Economy

Economy, as depicted in Fig. 3, refers to a number of characteristics, including innovative spirit, entrepreneurship, productivity, economic image, trademarks, flexibility of labor market, internationalization, local and global interconnectedness, effective production of goods and services for new business models, enhanced by connectivity through Information and Communication Technologies (ICTs) [8,15,19,39].

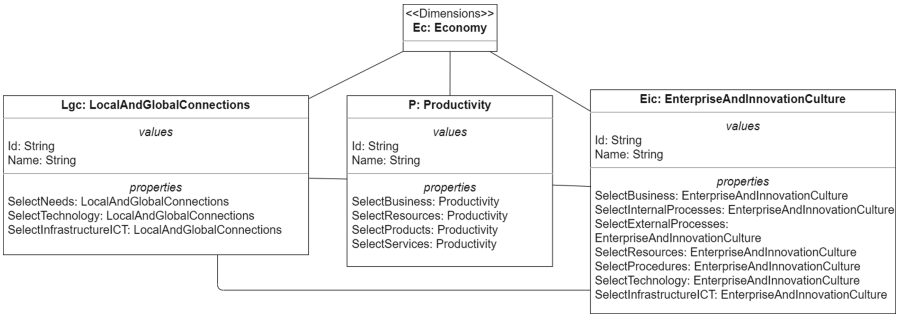


Fig. 3. SysML internal block diagram for the economy dimension of a Smart City.

The economy dimension requires a smart city to present many attributes such as entrepreneurial leadership, valuing creativity, preparing for the challenges and opportunities of economic globalization, as well as driving innovation, making strategic investments, standing out in productivity and flexibility, and insisting on balanced and sustainable economic development and growth [18].

4.3 Mobility

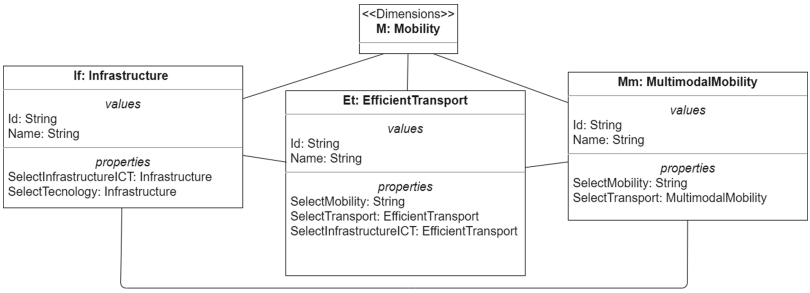


Fig. 4. SysML internal block diagram for the mobility dimension of a Smart City.

Mobility, as illustrated in Fig. 4, refers to sustainable innovative, safe transport systems, mixed modal access, logistics, and communication systems, availability of ICT infrastructure, local and international accessibility. Real-time information improves the management of public and personal mobility, increasing the use of appropriate mobility options and chains, for example, cars, trams, trains, subways, buses and bicycles [8,15,19,39].

The mobility dimension aims to facilitate the flexibility of people within a city, and consequently generates benefits including reduced traffic, reduced travel time and costs, reduced pollution and noise pollution, and greater safety during

travel. Furthermore, mobility can change constantly, have immediate communication with users of mobile applications and ensure an intelligent and smooth travel process [42].

4.4 Governance

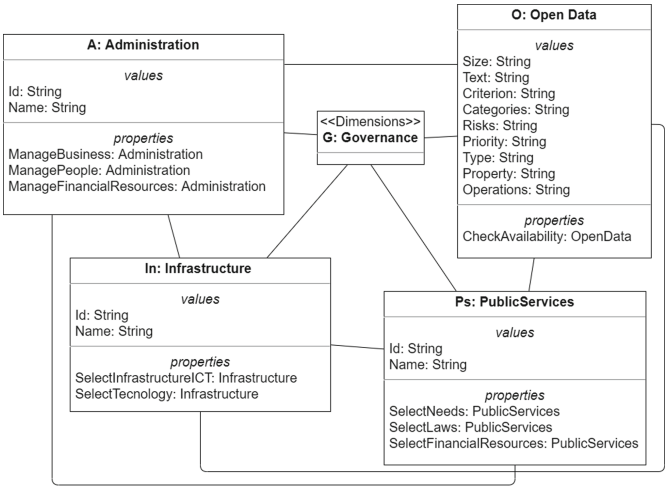


Fig. 5. SysML internal block diagram for the governance dimension of a Smart City.

Governance, as depicted in Fig. 5, refers to public strategies and policies, including urban planning, which enables the co-production of public services, that is, participation in decision-making, public and social services, transparent governance, and political strategies and perspectives. Governance needs to be a transparent process and open data that allows a variety of participation at different levels for decision-making. It is characterized by the orchestration and balance of processes, partnerships, networks, and formal, semi-formal, and informal spheres [8,15,19,39].

The governance dimension plays an important role in a smart city. Its goal is to better serve citizens and communities by linking data, institutions, procedures, and physical infrastructure based on ICT. Also, a smart government allows citizens to be involved in city planning and public decisions. Therefore, the smart government can improve efficiency at the same time as increasing the transparency of information [9].

4.5 Environment

Environment, as depicted in Fig. 6, refers to the care with natural resources and planetary culture, that is, it includes sustainable resource management, pollution

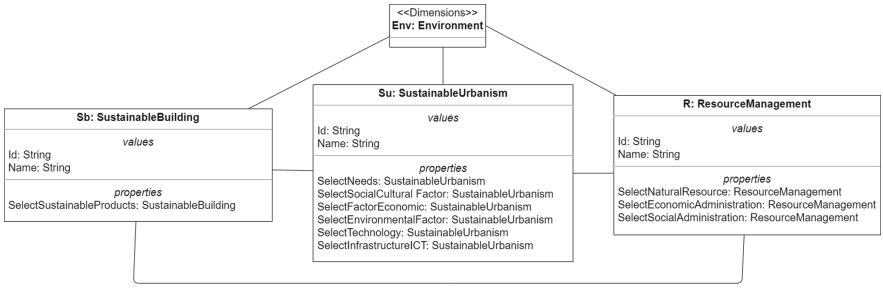


Fig. 6. SysML internal block diagram for the environment dimension of a Smart City.

reduction, and environmental protection with green construction, green urban planning, green production, green buildings, and consumption of green energy [8,15,19,39].

The environment dimension uses the technological resources to detect, act, communicate and enable the infrastructure and technologies to provide services, acquire and exploit knowledge about the environment, so that its citizens live and protect nature, as well as can adapt their preferences and needs [18,37].

4.6 Living

Living, as depicted in Fig. 7, refers to the quality of life and safe environments. It comprises infrastructure to support everyday life, which involves decent housing options, work opportunities, good health conditions, access to nature, touristic attractiveness, individual safety, housing quality, educational and cultural facilities incorporated into social cohesion, enhanced by co-governance [8,15,19,39].

The living dimension is considered a key element for the development and management of a smart city. The services provided by this dimension are based on ICT for the dissemination of information and the involvement of citizens in cultural activities and tourism [16,43].

5 Discussion

A smart city is an urban center that integrates a variety of solutions to mitigate problems generated by the growth of urbanization, improve the efficiency and performance of infrastructures, enable the quality of life of citizens living in these cities, and achieve sustainable urban development with focus on technology, human resources and collaboration of citizens for active governance.

The dimensions of a smart city have relevant factors that reflect the important aspects of each intelligent characteristic, for example, smart people have human and social capital, the smart environment has natural resources, the smart economy has competitiveness, smart mobility has transport and ICT,

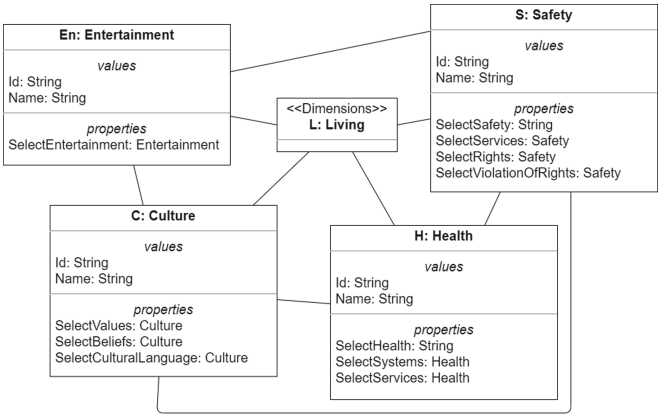


Fig. 7. SysML internal block diagram for the living dimension of a Smart City.

smart living has the quality of life, and smart governance has citizen participation.

In the literature, many modeling languages are used for modeling smart city software systems. In this article, SysML is used to model elements of systems that are not software, that is, elements of the dimensions of smart cities at a higher level of granularity in a complex system.

The SmartCitySysML Dimensions profile extension facilitates the use of common elements of smart city dimensions and provides a visual representation to assess the quality of the diagrams from a practical point of view. The conception of this extension arose from the need to think in different dimensions to separate interests and improve the focus on problem-solving.

This profile is extended from the SysML Internal Block Definition diagram and considers the dimensions thinking about modeling systems with SysML for smart cities. During the design process, some challenges related to formalism and consistency arose, mainly due to the lack of software tools that can fully implement all SysML resources.

Dimensions of the SmartCitySysML Dimensions profile, which includes people, governance, economy, mobility, environment, and living, were based on the dimensions presented by Cohen [8], Giffinger and Gudrun [15], Moustaka et al. [19] and Staffans and Horelli [39].

Table 1 illustrates the different dimensions described by various authors of a smart city. The authors of the dimensions are on the horizontal, and the dimensions are on the vertical. SmartCitySysML stands for the dimensions described by the authors of this article, GG stands for Giffinger and Gudrun [15], NP stands for Nam and Prado [22], R stands for Roche [32], N stands for Nilssen [23], and J stands for Jucevičius et al. [17].

In Table 1, it is possible to note that the areas related to dimensions of a smart city are not yet consolidated. For example, in SmartCitySysML, Giffinger and Gudrun [15], and Nam and Prado [22] the people dimension is presented.

Table 1. Dimensions for Smart City.

	SmartCitySysML	GG	NP	R	N	J
People	•	•	•			
Governance	•	•			•	
Economy	•	•				
Mobility	•	•				
Environment	•	•				
Living	•	•				
Technology			•	•	•	•
Institutions			•			
Intelligent				•		
Open				•		
Live				•		
Collaborative					•	
Experimental					•	
Agile						•
Learning						•
Knowledge-driven						•
Network						•
Innovation						•

In SmartCitySysML, Giffinger and Gudrun [15], and Nilssen [23] the governance dimension is presented, in the works of authors, Nam and Prado [22] and Nilssen [23] and Jucevičius et al. [17] the technology dimension is presented, and the other dimensions are presented only once.

It is worth noting that although the dimensions proposed by Giffinger and Gudrun [15] and the dimensions proposed in the SmartCitySysML profile are the same, they have different characteristics. The characteristics and factors of each dimension of the SmartCitySysML profile are described in Sect. 4, while the characteristics and factors proposed by Giffinger and Gudrun [15] are:

- Economy dimension: an innovative spirit, entrepreneurship, economic image and trademarks, productivity, the flexibility of labor market, international embeddedness, and ability to transform;
- People dimension: level of qualification, affinity to lifelong learning, social and ethnic plurality, flexibility, creativity, cosmopolitanism/open-mindedness, and participation in public life;
- Governance dimension: participation in decision-making, public and social services, transparent governance and political strategies and perspectives;
- Mobility dimension: local accessibility, national and international accessibility, availability of ICT-infrastructure and sustainable, innovative, and safe transport systems;

- Environment dimension: lack of pollution of natural conditions, pollution, environmental protection, and sustainable resource management;
- Living dimension: cultural facilities, health conditions, individual safety, housing quality, education facilities, touristic and social cohesion.

The proposal of this article is different from the articles illustrated in Table 1 for including the factors and characteristics of the dimensions of smart cities as native SysML components, adapting the language to represent the elements related to smart cities, using terminology well-known for stakeholders.

Another difference from the articles published by Barbieri et al. [2] and Reichwein et al. [28] is the creation of a SysML profile for smart cities, with the extension of the dimensions, to help in modeling the needs of applications in a smart city both in software design and architecture activities.

6 Conclusion

Modeling software systems for smart cities is a complex activity, as there is not a single standard to be used, since there are many modeling languages proposed in past years, and a diversity of problems and domains. Therefore, a variety of legacy software systems were developed using many different software modeling languages, which are mostly not tailored to express stakeholders' terminology.

The focus of this article is to adapt and extend a SysML profile for smart cities introduced in the article proposed by the authors themselves, named SmartCitySysML, to model systems for smart cities through several important dimensions for smart cities applications.

The proposed extension of the profile, SmartCitySysML Dimensions, arose from the need to think in different dimensions to identify various areas, separate interests, improve the focus of solving problems generated by the growth of urbanization, represent and facilitate the use of common elements of smart city dimensions and provide a visual representation to evaluate quality of the diagrams from a practical point of view.

The dimensions proposed in SmartCitySysML Dimensions were identified and described from characteristics and essential factors for a smart city to improve efficiency, sustainability, and quality of life of citizens of these cities. The SysML Internal Block diagram is used to model the profile dimensions.

It is worth mentioning that this work of developing a profile for smart cities is still in progress. Future work will focus on software modeling and simulation of various case studies of smart cities related to infrastructure systems, for example, traffic signal control, water and sewage treatment, energy, and health information systems.

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