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Artículo de revisión

Towards a measurement of smart and sustainable cities

Hacia una medición de las ciudades inteligentes y sostenibles

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Abstract

The term Smart or Sustainable City refers to a global trend that corresponds to the use of information technologies to transform cities into more liveable, viable and sustainable areas for their inhabitants. This article documentarily analyses several measurement models from different countries; ISO/IEEE standards, degrees of maturity, sustainable and inclusive development, environmental improvements, urban intelligence metrics, a "Smart Dashboard", as well as performance indicators to evaluate the success and progress of smart city projects. It analyses the results and provides a comparison of the measurement models and metrics evaluated, to assist in the development of policies and initiatives, to guide economic growth and social development of rural and urban communities. To propose a strategic guide that can be used for the design of smart and sustainable projects, to try to improve the quality of life of citizens.

Keywords: sustainable development, urban development, information society, urban areas, economic and social development, smart cities.
UNESCO code: 3329.99- Urban planning, smart cities.
CAPE code: 60502002- Urban planning methods and techniques.

Resumen

El término Smart City o Ciudad Sostenible se refiere a una tendencia global que corresponde al uso de las tecnologías de la información para transformar las ciudades en zonas más habitables, viables y sostenibles para sus habitantes. Este artículo analiza documentalmente varios modelos de medición de diferentes países; normas ISO/IEEE, grados de madurez, desarrollo sostenible e inclusivo, mejoras medioambientales, métricas de inteligencia urbana, un *Smart Dashboard*, así como indicadores de rendimiento para evaluar el éxito y el progreso de los proyectos de ciudades inteligentes. Analiza los resultados y proporciona una comparación de los modelos de medición y las métricas evaluadas, para ayudar al desarrollo de políticas e iniciativas, guiar el crecimiento económico y el desarrollo social de las comunidades rurales y urbanas. Proponer una guía estratégica que pueda ser utilizada para el diseño de proyectos inteligentes y sostenibles, para mejorar la calidad de vida de los ciudadanos.

Palabras clave: desarrollo sostenible, desarrollo urbano, sociedad de la información, desarrollo económico y social, ciudades inteligentes.
Código UNESCO: 3329.99 - Planificación urbana, ciudades inteligentes.
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1. Introduction

Smart Cities is a global movement focused on transforming cities into more livable, viable and sustainable urban areas within an ecosystem of technologies and services based on the citizen, an urban strategy that uses technology and promises to improve the quality of life of citizens. Significant growth in the world's urban population is expected to drive sustainability, resource conservation, and economic and technological development initiatives. Cities will evolve to attract and retain investments, businesses, residents, and visitors; however, few practices are known where cities measure the impact of smart initiatives on the daily lives of their inhabitants [1].

As the term "smart city" gains more and more traction, there is still confusion about what a smart city is, especially since several similar terms are often used interchangeably. On the one hand, there is talk of ecosystems that drive the cross-industry of applications such as connected vehicles, smart grids, connected health care and connection of the workforce, among others.

On the other hand, Smart Cities do not follow a pattern or cannot be compared with each other in a simple way, due to this, elements and methods have been used to obtain an evaluation of the level of maturity of these cities.

For this reason, a series of proposals and standard norms have been developed, such as the SCMM (Smart City Maturity Model) or the maturity model of a Smart City, which is inspired by the maturity indices of the CMMI (Capability Maturity Model Integration). There are also the standards like the ISO 37120, 37121 and 37122 (Smart City Maturity Model) and the ISO Technical Report ISO/TR 37150 and 37151 focused on metrics for "smart and sustainable" community infrastructures [2], [3].

Researcher Jim Frazer, from the IEEE Smart Cities committee, focuses its measurement using the proposed IEEE P2784 Smart City Planning and Technology standard on five factors: social, technological, economic, environmental, and political, considering the human and social needs of users, applications, and technologies, with current opportunities and challenges facing smart city advocates, implementation specialists, the public, and other interested communities [4].

This paper aims to use the term "smart" in the context of cities based on a documentary review of different international standards and norms that identify the main dimensions and elements that characterize a smart and sustainable city from the analysis of case studies in different countries, to create a methodological guide that defines a set of criteria to measure a smart city [5].

The first section of this article is the introduction, the second explain the Smart Cities concept, the third part talks about the different approaches related to the measurement methods used in some countries. The fourth section continues with the assessment and standards for metrics for smart community infrastructures. The fifth section includes comparison of models and methods of measurement and evaluation of Smart Cities.

The sixth section makes a mapping of characteristics regarding Smart measurement methods and criteria looking for measure different organizations including Government, Public Institutions, Private Companies and Universities. Finally, a conclusion section gives a summary of the references.

2. Development

2.1 Methodology

This research is built from a qualitative approach, and aims to retrieve, organize, and analyze relevant information for the evaluation of smart cities, in the sense of constituting a kind of strategic guide that summarizes the aspects that can be valued for different countries, organizations and institutions.

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In the first phase of the methodological route, data collection was carried out through the exhaustive documentary review technique, from which some of the main theoretical approaches anchored to the concept were reviewed and identified.

The documentary review was executed with different databases, although the research will focus on analysing two specifically platforms such as IEEE Future Networks and IEEE Resources Center Content. The main objective of the search is to find documents and articles related to case studies and theoretical references linked to the subject to meet the research objective.

The elaboration of the information search and selection of documents related to the following four areas 1) Smart cities, 2) Territorial planning and sustainability, 3) Application of standards, procedures, and models and 4) Technology and society. For which a series of documents were found related to case studies on smart cities, application of standards and measurements to smart cities, as well as research on territorial, urban and sustainable planning. In addition, documents related to the link between technology and society was reviewed.

This review allowed identifying and extracting important indicators in specialized literature, international standards, and norms. In turn, this classification helps to define the theoretical notion of smart cities to the extent that it reflects their practical implications for societies.

About the data obtained in the collection phase is taken up again to carry out a comparative analysis based on the measurement of indicators and models related to smart cities and their application for comparison in different regions. To carry out this comparative analysis, the following criteria were used to define the models to be used for this research 1) urban sustainability, 2) operability and systems of a smart city, 3) application of performance measurement evaluation, 4) use of different technologies and 5) use of metrics and indicators. In other words, the selected models must meet at least one of the above criteria.

It is also important to emphasize that the countries chosen for this comparison are Finland, Brazil, United States, Indonesia, Turkey, Sweden, China, Canada and Ecuador because these countries have shown in recent years a significant progress in the creation of smart cities and also, as mentioned by Alderete, several existing indexes or rankings of smart cities select cities based on the size of their population, as these possess attributes characteristic to their size, the challenges faced by these large cities, greater availability of human capital, greater infrastructure in terms of electricity, water and telecommunications, greater use of ICT or other characteristics, these being countries that possess large cities and resources to implement models to create smart cities [6].

In this phase, starting from the contrast and comparison between measurement and evaluation models, cases of national, urban, and organizational experiences are explored, where the typologies of both qualitative and quantitative indicators are oriented to the measurement and evaluation of fundamental aspects of smart cities.

This resulted in the subtraction of criteria for measuring a smart city, list of indicators and metrics and the measurement of smart organizations, which allowed a mapping to define the theoretical notion of smart cities as it reflects its practical implications for societies. Furthermore, the models and metrics considered, as well as the summary table elaborated, form a strategic guide that will orient the design of smart and sustainable projects to achieve a Smart and Sustainable Cities measurement.

2.2 About smart cities

As a result of the analysis of the case studies for this research, the following criteria are proposed as a methodological guide to measure a smart city. The proposal is based on the documentary analysis reviewed in this research. For which the following five areas are generated for the guide.

- Characteristics of a smart city: defines the main characteristics of a smart city.
- Criteria of a smart city: determines what criteria a city should consider becoming a smart city.
- Measuring a smart city: establishes the indicators and criteria to measure a city.
- Situation of the region on smart cities

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- Measurement of organizations: it describes the models and metrics that should be considered depending on the type of organization to create smart initiatives and projects.

a. Understanding smart cities

According to IEEE Future Networks researchers, the main areas of applications and services (Fig. 1) that make up Smart Cities are: energy, water, mobility, vehicles, health, agriculture, and waste management; supporting ecosystems are: agriculture, education, electricity, public health, media and entertainment, security, transportation, water distribution, waste, and recycling [3], [7].

A Smart City can encompass both urban and rural areas, developing energy efficient buildings, remote surgeries, mobility with air vehicles, improved urban services, precision agriculture, together with the development of autonomous vehicle applications and power grids and also serve as an intersection between citizens with the government and its policies; with automation initiatives, digital transformation and management of its operations, in order to offer value to citizens, as a people-centred approach [5].

Figure 1: Smart City Applications and Services [7].

In agreement Narendra Mangra and Rose Qingyang Hu [8], a Smart City is an urban infrastructure that connects people with the environment, but also connects people with people, where it seeks to make cities more efficient, more functional and at a lower cost [8]. Future network, 5G/6G wireless technology generations, are expected to enable fundamentally new applications that will transform the way humanity lives, works, and engages with its environment in cities, and will see the evolution of applications and services that extend beyond cities to include "Smart Regions", reaching urban and non-urban areas [8].

In the same way to Sumita Sarma of the University of Missouri, the common goal of implementing smart cities is to drive economic growth and social development in the community, facilitating collaborative dialogue and innovations in technology [9].

Francesco Paolo Appio, from the Léonard de Vinci Pôle Universitaire research center in France, perceives smart cities as "Smart Communities" or collaborative ecosystems that facilitate innovation, creating links between citizens, government, companies, and educational institutions. It also adds that smart cities strive to increase the competitiveness of local communities through innovation, as well as increase the quality of life of their citizens through better public services and a cleaner environment. To achieve these goals, smart cities rely on cutting-edge information technologies [10].

Everton Cavalcante, from the Federal University of Rio Grande do Norte, Brazil, defines a Smart City as a Systems of Systems approach (SoS); a set of independent and heterogeneous complex systems,

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spanning multiple distributed systems and participating in complex relationships, including integration and interaction with other systems to provide new functionality [11].

Simon Bibri from Trondheim, Norway, argues that a strategic objective of smart cities is to improve sustainability with the help of technologies, so a sustainable smart city model or a framework for sustainable and smart urban development is recommended [12].

b. Evaluating smart and sustainable cities: case of Finland

City assessment tools are being used to support decision-making in urban planning and development as they provide assessment methodologies for cities to show progress towards defined goals.

Researcher Hannele Ahvenniemi from Finland conducted a study between sustainable and smart cities using 16 sets of assessment frameworks (eight smart city assessment frameworks and eight urban sustainability assessment frameworks). [13].

In her results, researcher Ahvenniemi concludes that there is a much stronger focus on modern technologies and "intelligence" towards smart city frameworks compared to urban sustainability frameworks. One of their arguments is that urban sustainability frameworks contain many indicators that measure environmental sustainability, while smart city frameworks lack environmental indicators while highlighting, on the other hand, social and economic aspects.

She recommends that for an evaluation of the performance of smart cities not only production indicators that measure the efficiency of the deployment of smart solutions be used, but also impact indicators that measure the contribution to the final objectives, such as environmental, economic, or social sustainability [13].

c. Smart Cities measurement

IEEE Smart Cities researchers agree that smart cities waste less, offer a better quality of life, and ensure a brighter future for the next generation, but how can they tell if their actions are making a difference? There are already models that allow measuring the degree of a smart city, via some maturity pattern necessary to measure the level of intelligence of a Smart City. However, most of the indicators used in cities do not follow a pattern or it is difficult to compare them with each other.

In this sense, several reference frameworks and standards have been developed to provide a set of metrics and indicators as a recommendation of what to choose and how it should be measured to determine the degree of maturity and contribute to improving the contribution of communities to the sustainable development of a Smart City.

d. SMM - Sustainability Maturity Model

Researcher Eber da Silva de Santana, from UNIFACS, University of Salvador in Bahia, Brazil, proposes the SMM (Sustainability Maturity Model) option as a sustainable model to measure the maturity of a city, using three different sources, as inspiration:

- CMMI (Capability Maturity Model Integration) as a capacity maturity model,
- COBIT (Control Objectives for Information and related Technology) used for Project Management Control,
- ISO 37122 with indicators for Smart Cities [14].

The ISO 37122 standard recommends that, to evaluate a city, it must be reflected in at least 50% of the list of indicators [15]. For this study, researcher Santana selected 45 of the 75 available indicators, covering 60% and he grouped the results into six domains and applied an assessment with indicators of compliance with the subject areas evaluated.

The following Table 1 shows the results of applying the model in the smart domains: economy, people, governance, mobility, environment, and life, and for each of them, the researcher Santana applied a

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questionnaire to quantify the level of maturity (CMMI) corresponding to the degree of sustainability of a city [14], [16], [17].

Table 1: Smart City Domains and Metrics [14].

Domain	Hits %
Smart Economy	100%
Smart People	80%
Smart Governance	60%
Smart Mobility	64%
Smart Environment	90%
Smart Living	66%

Source: own authorship.

e. ISO 37150 and 37151 standards for metrics for smart community infrastructures

The technical standard ISO 37150 (Community Infrastructures) offers metrics for community "smart infrastructures" and provides guidance for further standardization in this area (see Fig. 2).The community infrastructures incorporated in this ISO Standard are energy, water, waste, transport, information, and communication technologies, which have been optimized considering sustainable development and resilience. About the ISO/TS 37151 describes 14 categories of basic community needs (from the perspective of residents, city managers and the environment [2]).

Figure 2: Metrics in ISO Technical Report ISO/TR 37150 [2].

All of them serve to support communities and have a significant impact on economic and social development, as a means of ensuring the delivery of goods and services that promote the prosperity and growth of a city. The ISO metrics not only support city and community managers in planning and measuring performance, but also help to compare and select proposals for the acquisition of products and services aimed at improving community infrastructures.

f. Measuring urban sustainability: case of USA

Researcher Igor Vojnovic, from Michigan State University, indicates that practically all population growth over the next three decades is expected to take place in cities, exerting pressure and with evolving socio-ecological conditions. and reflecting, in part, the global interest in urban sustainability. Vojnovic affirms that all these elements limit our progress towards the condition of urban sustainability and proposes to apply an approach of two variables: one, the limited understanding of science, sustainability, or lack of

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commitment and two, the fear of governments to achieve the development of their communities with urban sustainability [17].

g. Qualitative indicators for a smart economy: case of Indonesia

Indonesia is undergoing a historic change and is beginning to enter the urban economic stage, where cities are growing faster than cities in other Asian countries, so it becomes interesting to use metrics to implement the concept of smart economy [17]. Researcher Indrawati, from West Java, Indonesia, using qualitative methods, analysed the city of Bandung in Indonesia, where he has identified the way to measure whether a city has implemented the concept of smart economy, and with it, has managed to formulate a model that can be used to measure smart technology in other cities in Indonesia [20].

h. Operational aspects of smart cities: case of Turkey

Professor Ebru Tekin Bilbil, of Urban Policy of Turkey, has made efforts to design concept maps and models that better describe the definition, typologies, and dimensions of cities in Turkey, where Information and Communication Technologies (ICT) were used, achieving a further advance in the concept of "smart city" [21]. According with the professor Bilbil focused on identifying the weaknesses, contradictions and limitations of smart city projects and action plans prescribed by policy reports to understand how smart city projects work.She conducted the study of Turkey's initiative, which began in the 2000s, on the transition to an information society, as well as its smart city initiatives starting in the 2010s.

In addition, she managed to identify intelligent projects based on the context and differential aspects on the experiences of intelligent solutions, and proposed a process with dynamics that create, transform and design new reconfigurations in socio-technical platforms, to create a roadmap for other related projects at the national level [21].

- Infrastructure dimensions (legal and technological basis and coordination between institutions).
- Policy areas.
- Critical performance indicators to assess the success and progress of smart city projects.

2.3 Smart Cities assessment models

a. Evaluating the performance of a Smart City: case of Indonesia

Researcher Abdurahman Musbah, from Negeri University in Jakarta, Indonesia, proposes two approaches to assessing performance: one, using relational income (RR) to study the process of value creation in an inter-organizational context using TQM (Total Quality Management) to measure the performance of the smart city [22]. Aleksander Orlowski, from the Gdansk Faculty of Management and Economics at the University of Technology, Poland, says municipalities require a new approach to the evaluation of smart cities and collaborates by preparing municipalities to turn them into smart cities [23]. Professor Orlowski bases his results on studies carried out over two years in ten large municipalities with measurements of the relationship between the preparation and maturity of the organization [23]. Both studies are compared with the Smart City evaluation methods used by other researchers in terms of ISO classifications or standards.

b. Urban Smart Dashboard to measure the performance of a Smart City: case of Italy

According to Dameri from the University of Genoa, Italy, suggests the use of a Smart Dashboard to measure the performance of smart cities and assess the ability of a smart strategy to impact the quality of life of citizens [24]. She adds that smart cities require multidisciplinary urban strategies, involving various technical applications and public and individual behaviours, and proposes five steps to build the dashboard for Smart Cities (Fig. 3):

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- Definition of the smart city value chain.
- Selection of performance indicators.
- Construction of the smart dashboard.
- Implementation of the smart city dashboard.
- Scalability and sustainability.

Figure 3: Dashboard for Smart Cities.

Additionally, Professor Dameri comments that all smart city initiatives are grouped into a few domains, being the urgent ones: reducing the environmental footprint of the city, improving the efficiency and effectiveness of public services, and improving the innovative spirit, entrepreneurship, and culture of the city [24].

c. A systems perspective for a Smart City: cases of Brazil and Sweden

Everton Cavalcante, from the Federal University of Rio Grande do Norte in Natal, Brazil, says smart cities are made up of ecosystems and encompass several distributed systems with complex relationships, which integrate and interact with other systems to provide new functionalities. These relationships are referred to as systems of systems (SoS) and can be analysed as a generalized set of independent and heterogeneous complex systems, which collaborate with each other to fulfil common global missions within a city [11].

As mentioned Colding, from the Resilience Centre at Stockholm University, Sweden, focuses on how current trends in urban design and architecture are inclined to prioritise high-tech solutions at the expense of low-tech functionalities and prefers to omit information and communication technology [25]. Also says that sustainable urban planning faces three major challenges:

- Mitigating global warming and other global environmental problems by reducing the energy of cities
- Maintaining socio-ecological systems and services that provide resilience in the face of unforeseen impacts and risks.
- Provide environments that support the health and well-being of city inhabitants.

The solutions of the researcher Colding are rather based on nature, seeking to make cities smarter, safeguarding biodiversity and the provision of ecosystem services, and at the same time, promoting adaptation to climate change [25].

d. Assessing Smart Cities in China using the Internet of Things (IoT): case of China

Professor Tao Song of the Chinese Academy of Sciences in Beijing says that in recent years, smart technologies, and networking solutions, such as the Internet of Things (IoT), have been adopted by most of China's leading cities as ways to reinvigorated economic opportunities and strengthen their global resilience to climate change [26].

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The smart city concept, according to Song, serves as a complex system that allows for the integration of sensors, data, applications, and organizational forms to make cities more agile and sustainable when faced with global climate change. Six key conceptual dimensions of smart city practices are classified: energy, agriculture, transportation, buildings, urban services, and urban security operations.

Chinese smart city policies and practices explore energy and renewable resources, increase public convenience, and make cities more comfortable and citizen friendly. Critical concerns are explored in areas such as integration (within the urban system, with other cities), governance, innovation, and finance. Finally, according to Professor Song, a political vision is required to build public-private collaboration networks, encourage more innovations and investments in smart city initiatives, and put more emphasis on smart services [26].

e. Innovative metrics for smarter and more responsive cities: case of Canada

According to H. Patricia McKenna of AmbientEase, in Victoria, British Columbia, Canada, there is an emerging and evolving landscape of smart city metrics in relation to Big Data challenges. Researcher McKenna based on a review of the literature, the problem of synthetic quantitative indicators is identified along with concerns about measuring urban realities and making metrics meaningful [27].

It becomes necessary, McKenna says, to move forward with innovative metrics for smarter, more interactive, and responsive cities to address and mitigate algorithm-related challenges on the one hand, and concerns associated with engaging people more meaningfully on the other. Researcher McKenna used multiple methods of data collection, surveys, and interviews, employing a combination of content analysis for qualitative data and descriptive statistics for quantitative data.

The main findings support the need to rethink and innovate metrics, highlighting the potential opportunity to develop new pathways and spaces to engage people more directly in defining urban metrics [27].

f. Measuring the performance of a city: case of Ecuador

According with Professor Teresa Guarda, from the State University of the Santa Elena Peninsula, La Libertad, in Ecuador, says that the main objective of the smart cities' initiative is to allow it to manage its assets efficiently, betting on innovation and creativity, to promote sustainable and inclusive urban development.

When talking about an emerging and promising area such as smart cities, the topic of performance measurement has gained more relevance. The performance of smart cities involves measuring the progress of a territory, in terms of its ability to provide a better quality of life to its citizens [28].

It is necessary to understand the territorial specificities, and to know to what extent technologies can be useful to carry out a sustainable transition. It is in this context, according to Professor Guarda, that the objective is to evaluate what technologies the citizens of the urban territory in the province of Santa Elena in Ecuador have, to measure the intelligent performance of that city [28].

2.4 Results and discussion

a. Comparing models and methods of measurement and evaluation of Smart Cities: Improve city services and quality of life based on ISO 37120

Today, many mayors of cities around the world claim that their city is transforming to be Smart City only because they have ICT-based initiatives for the city and start from different starting points and, until today, the perception of smart city is very broad.

As an aid, we have the ISO 37120:2014 standard (Sustainable Development of Communities - Indicators for city services and quality of life). This standard is applicable to any city, municipality or

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local government that commits to measuring its performance in a comparable and verifiable manner, regardless of its size and location [29].

The ISO 37120 standard, together with 37122 and 37123, provide a framework for Smart and Sustainable Cities (see Fig. 4). This ISO standard does not care whether the city is Smart or otherwise and proposes a step-by-step process to identify ICT-related initiatives for each of the ISO 37120 indicators. The result is the list of initiatives that can be applicable for the city manager to move the city to the next better level [29].

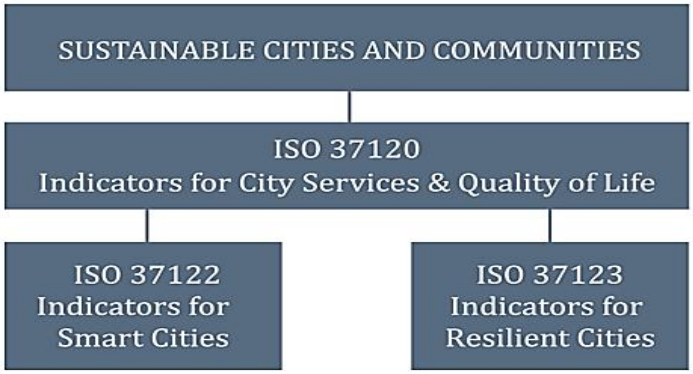

Figure 4: ISO Standard of Indicators for Smart and Sustainable Cities [29].

ISO 37122 establishes indicators with definitions and methodologies to measure Smart Cities and consider aspects and practices that drastically increase the rate at which cities improve their social, economic, and environmental sustainability outcomes [15].

This set of standards serves as a fundamental guide for accelerating improvements in city services and quality of life, as well as for the definition of a smart city, and aims to provide a comprehensive set of indicators to measure progress towards a smart city [29].

b. Mapping results:

- *Characteristics of a Smart City*. From the concept of Smart Cities, according to the definitions of smart city are diverse. As the concept is becoming popularly known but is used around the world under different names and in different circumstances. Therefore, the following table will refer to the characteristics of a smart city [30].The Table 2 refers to the different characteristics that a Smart City has, according to the criteria mentioned by the different authors analyzed. The different regions of the world are grouped and compared with standards as columns in the Table 2.

  Notice that the term transform cities into more livable urban areas is the most referenced by the authors in all the regions, and where there is a greater coincidence with respect to measuring a Smart City.

  ISO 37120 contains the domains of a Smart City (economy, people, governance, mobility, environment, and life), and the Standards 37122 and 37123 form a reference framework for analyzing smart cities, and rely on the ecosystems of agriculture, education, electricity, public health, media and entertainment, security, transport, water distribution, waste, and recycling.

  ISO 37150 contains metrics for "smart" community infrastructure (energy, water, waste, transport, ICT). In addition to the IEEE P2784 standard on Smart City Planning and with the Smart Dashboard, an opportunity is created to manage smart investments and projects. Together, both incorporate qualitative and quantitative metrics that measure the state of assets, ecosystems, and domains, with the central idea of making these metrics meaningful and useful for the community and providing smart, sustainable cities with quality of life for citizens.

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Table 2: Characteristics of a Smart City by region.

Characteristics of a Smart City	ISO IEEE	NA LA	EU	AS
- Increases the competitiveness of communities.			X	
- More efficient, more functional, and lower cost cities.		X		
- Connect people with the environment and with technology.	X			
- Set of independent and heterogeneous systems.				X
- Collaborative ecosystems.	X		X	X
- Facilitates dialogue and innovation in technology.		X		
- Boosts economic growth and social development.		X		
- Urban infrastructure connects people with the environment.	X			
- Framework for sustainable and smart urban development.			X	X
- Transform cities into more livable urban areas.	X	X	X	X
- Transform the way citizens live and work.	X			X
- Links between citizens with government, business, and academia.			X	

Note: a letter "X" indicates the matches of characteristics found in such regions, according with the authors evaluated.
ISO-IEEE: Standards from ISO and IEEE institutions,
NA-LA: North America and Latin America,
EU: Europe,
AS: Asia.

Source: own authorship.

- *Measuring a Smart City*. The following Table 3 refers to the different metrics and indicators that a Smart City has, according to the criteria mentioned by the authors analysed. The Table 3 contains a list of indicators and metrics taken from the authors and referenced in the different regions. The letter "X" that appears in many of the Measurement criteria are Governance Indicators and Conceptual Maps with 2 references by the authors evaluated. Most of the cells show a single coincidence in those regions as a unique initiative of the specific region.

- *Measuring the organizations.* The next Table 4 analyze the types of organizations: Government Institutions and Municipalities, Decentralized, autonomous public institutions, Private companies offering services to government and public institutions, Educational institutions, universities, private academies, and research centers.

The main idea of using Table 4 is to select the models and metrics that allow planning, evaluating, and managing the smart initiatives and projects of the different types of organizations.

The first column of the Table 4 contains a list of indicators and metrics, and the columns are the different types of organizations mapped: Government (Gov), Public entities (Pub), Private companies (Priv) and educational institutions (Edu).The letter "X" in cell means a coincidence of the approach to be used in the organizations, the greater number of coincidences, the more it is recommended in the organization types. There is a uniformity of metrics, techniques, and methods valid mainly for government and public service institutions, as well as useful measurement methods for the private and academy types of organizations.

The most referenced are: with four references: Smart Economy metrics, Critical Performance Indicators, and the Smart Dashboard; with three references: Qualitative Indicators, Quantitative indicators, and Internet of Things (IoT).

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Table 3: Measurement criteria of a Smart City.

Measuring a Smart City	NA	LA	EU	AS
- RR (Relational Income) approach: creating value in an inter-organizational context.		X		
- TQM (Total Quality Management) approach: measures performance.				X
- Governance indicators: efficient asset management, limited understanding of science, sustainability, lack of commitment, fear of achieving the development of their communities.	X	X		
- Critical performance indicators: evaluate the success and progress of projects.				X
- Quantitative indicators: descriptive statistics for quantitative data, measuring urban realities that are significant.	X			X
- Production indicators: efficiency in the deployment of intelligent solutions.				X
- Internet of Things (IoT): sensors, data, applications in the domains (energy, agriculture, transport, buildings, services, and urban security).				X
- Conceptual maps: definition, typologies and dimensions of cities, territorial specificities.		X		X
- SMM model maturity and degree of sustainability, domains: Economy, People, Governance, Mobility, Environment and Life.		X		
- Smart projects: policy scope, weaknesses, contradictions, constraints and action plans, legal and technological infrastructure dimensions, and inter-institutional coordination.				X
- Socio-ecological services: resilience to unforeseen impacts and risks and environments that support health and well-being.				
- System of Systems (SoS): independent and heterogeneous, fulfill global missions within a city.		X	X	
- Smart Dashboard: mobility, environment, people, housing, governance, and economy.			X	

Source: own authorship.

Table 4: Measurement of Smart Organizations.

Measuring a Smart Organization	Gov	Pub	Priv	Edu
- RR (Relational Income) approach: creating value in an inter-organizational context.	X	X		
- TQM (Total Quality Management) approach: measures performance.			X	X
- Governance indicators: efficient asset management, limited understanding of science, sustainability, lack of commitment, fear of achieving the development of their communities.	X			
- Critical performance indicators: evaluate the success and progress of projects.	X	X	X	X
- Quantitative indicators: descriptive statistics for quantitative data, measuring urban realities that are significant.	X	X	X	
- Production indicators: efficiency in the deployment of intelligent solutions.			X	X
- Internet of Things (IoT): sensors, data, applications in the domains (energy, agriculture, transport, buildings, services, and urban security).		X	X	X
- Conceptual maps: definition, typologies and dimensions of cities, territorial specificities.	X			X
- SMM model maturity and degree of sustainability, domains: Economy, People, Governance, Mobility, Environment and Life.	X			X
- Smart projects: policy scope, weaknesses, contradictions, constraints and action plans, legal and technological infrastructure dimensions, and inter-institutional coordination.	X	X	X	X
- Socio-ecological services: resilience to unforeseen impacts and risks and environments that support health and well-being.	X	X		
- System of Systems (SoS): independent and heterogeneous, fulfill global missions within a city.			X	X
- Smart Dashboard: mobility, environment, people, housing, governance, and economy.	X	X	X	X

Gov - Government Institutions and Municipalities.
Pub - Decentralized, autonomous public institutions.
Priv - Private companies offering services to government and public institutions.
Edu - Educational institutions, universities, private academies, and research centers.

Source: own authorship.

3. Conclusions

Smart Communities can be visualized as an urban strategy that uses technology and promises to improve the quality of life of citizens. A set of collaborative ecosystems that facilitate innovation, linking citizens with spaces to propose a government technology policy, and an opportunity for innovation integrating commerce, tourism, industry, and educational institutions.

All the three tables mentioned can be used as a frame of reference to analyze Cities and Organizations, useful models, and techniques to measure maturity and others to help on the planning, development of initiatives and monitoring smart projects for the inhabitants of a city as a target central to a smart and sustainable city.

The growing number of the world's population and high levels of urbanization require governments to seek more efficient ways to solve urban problems. However, the gap between the definitions suggests that it is necessary to further develop the measurement frameworks of a smart city or to redefine the concept of smart city.

References

[1] N. Mangra and A. Ghasempour, "Smart Cities: Connected Ecosystem of Ecosystems.", https://futurenetworks.ieee.org

[2] ISO Technical Report ISO/TR 37150, "Smart community infrastructures Lessons learned International Organization for Standardization," 2014. www.iso.org

[3] IEEE Future Networks, "International Network Generations Roadmap - Executive Summary," 2021. Accessed: Sep. 15, 2021. https://futurenetworks.ieee.org/images/files/pdf/INGR_2021_Edition/IEEE_INGR_Executive_Summary_2021Ed.pdf

[4] J. Frazer, "Exploring the IEEE Smart City Planning and Technology Standard P2784," Smart City Planning & Technology Standard Series, Sep. 10, 2019. https://resourcecenter.smartcities.ieee.org/education/webinar-videos/SMCWEB0100.html

[5] V. Albino, U. Berardi, and R. M. Dangelico, "Smart cities: Definitions, dimensions, performance, and initiatives," *Journal of Urban Technology*, vol. 22, no. 1, pp. 3–21, 2015, doi: 10.1080/10630732.2014.942092.

[6] M. V. Alderete. "What factors influence the construction of smart cities? A multilevel model with city- and country-level data." Ibero-American Journal of Science, Technology and Society, 2019, Vol. 14, no.41, pp.71-89. https://www.redalyc.org/articulo.oa?id=92460273005

[7] IEEE Future Networks, "International Network Generations Roadmap - Applications and Services," 2021. https://futurenetworks.ieee.org/images/files/pdf/INGR_2021_Edition/IEEE_INGR_AppsSvcs_2021Ed_Promo.pdf

[8] N. Mangra and R. Qingyang Hu, "IEEE International Network Generations Roadmap - Executive Summary," Sep. 2021. https://futurenetworks.ieee.org/images/files/pdf/INGR_2021_Edition/IEEE_INGR_Executive_Summary_2021Ed.pdf

[9] S. Sarma and S. A. Sunny, "Civic entrepreneurial ecosystems: Smart city emergence in Kansas City," Business Horizons, vol. 60, no. 6, 2017, doi: 10.1016/j.bushor.2017.07.010.

[10] F. P. Appio, M. Lima, and S. Paroutis, "Understanding Smart Cities: Innovation ecosystems, technological advancements, and societal challenges," Technological Forecasting and Social Change, vol. 142, 2019, doi: 10.1016/j.techfore.2018.12.018.

[11] E. Cavalcante, N. Cacho, F. Lopes, T. Batista, and F. Oquendo, "Thinking Smart Cities as Systems-of-Systems: A Perspective Study," Dec. 2016. doi: 10.1145/3009912.3009918.

[12] S. E. Bibri and J. Krogstie, "Smart sustainable cities of the future: An extensive interdisciplinary literature review," Sustainable Cities and Society, vol. 31. 2017. doi: 10.1016/j.scs.2017.02.016.

[13] H. Ahvenniemi, A. Huovila, I. Pinto-Seppä, and M. Airaksinen, "What are the differences between sustainable and smart cities?," Cities, vol. 60, 2017, doi: 10.1016/j.cities.2016.09.009.

[14] E. da S. de Santana, É. de O. Nunes, D. C. Passos, and L. B. Santos, "SMM: A Maturity Model of Smart Cities Based on Sustainability Indicators of the ISO 37122," International Journal of Advanced Engineering Research and Science, vol. 6, no. 2, 2019, doi: 10.22161/ijaers.6.2.2.

[15] I. O. for S. ISO, "ISO/FDIS 37122:2019 Sustainable cities and communities - Indicators for smart cities," Iso, vol. 2019, 2019.

[16] M. Paulk, "Capability Maturity Model for Software," in Encyclopedia of Software Engineering, 2002. doi: 10.1002/0471028959.sof589.

[17] E. W. N. Bernroider and M. Ivanov, "IT project management control and the Control Objectives for IT and related Technology (CobiT) framework," *International Journal of Project Management*, vol. 29, no. 3, 2011, doi: 10.1016/j.ijproman.2010.03.002.

[18] I. Vojnovic, "Urban sustainability: Research, politics, policy and practice," *Cities*, vol. 41, 2014, doi: 10.1016/j.cities.2014.06.002.

[19] Indrawati, N. Azkalhaq, and H. Amani, "Indicators to measure smart economy: An Indonesian perspective," in ACM International Conference Proceeding Series, Sep. 2018, pp. 173–179. doi: 10.1145/3278252.3278278.

[20] I. Indrawati, M. Y. Febrianta, and H. Amani, "Identification of e-government indicators for measuring smart governance in Bandung City, Indonesia," in Advances in Business, Management and Entrepreneurship, 2020. doi: 10.1201/9780429295348-189.

[21] E. Tekin Bilbil, "The Operationalizing Aspects of Smart Cities: the Case of Turkey's Smart Strategies," Journal of the Knowledge Economy, vol. 8, no. 3, pp 1032-1048, 2017, doi: 10.1007/s13132-016-0423-3.

[22] A. Musbah, A. Furjani, and K. Washington, "The Smart City How to Evaluate Performance," 2017.

[23] A. Orlowski, "Smart Cities Concept - Readiness of City Halls as a Measure of Reaching a Smart City Perception," Cybernetics and Systems, vol. 52, no. 5, 2021, https://doi.org/10.1080/01969722.2020.1871224

[24] R. P. Dameri, "Urban Smart Dashboard. Measuring Smart City Performance," 2017. doi: 10.1007/978-3-319-45766-6_4.

[25] J. Colding et al., "Applying a Systems Perspective on the Notion of the Smart City," Smart Cities, vol. 3, no. 2, pp. 420–429, May 2020, https://doi.org/10.3390/smartcities3020022

[26] T. Song, J. Cai, T. Chahine, and L. Li, "Towards Smart Cities by Internet of Things (IoT)—a Silent Revolution in China," Journal of the Knowledge Economy, vol. 12, no. 2, 2021, doi: 10.1007/s13132-017-0493-x.

[27] H. Patricia Mckenna, "Innovating metrics for smarter, responsive cities," Data, vol. 4, no. 1, 2019, https://doi.org/10.3390/data4010025

[28] T. Guarda, I. Lopes, P. Oliveira, M. I. Ribeiro, and A. J. Fernandes, "How to measure the performance of a smart city," in CEUR Workshop Proceedings, 2020, vol. 2714.

[29] A. Arman, A. Abbas, and R. Hurriyati, "Analysis of smart city technology initiatives for city manager to improve city services and quality of life based on ISO 37120," in ACM International Conference Proceeding Series, 2015, November. https://doi.org/10.1145/2846012.2846025

[30] Nam. T and Pardo.T, "Conceptualizing smart city with dimensions of technology, people, and institutions"in The Proceedings of the 12th Annual International Conference on Digital Government Research, June 12 - 15, pp 282-291, 2011. https://doi.org/10.1145/2037556.2037602

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