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Smart Cities, Sustainability, and Quality of Life
A comparison of indexes and the indicators they include

João Vitor Souza TEIXEIRA
Renata Maria Abrantes BARACHO
Architecture School, Universidade Federal de Minas Gerais
Belo Horizonte, Minas Gerais, Brazil

Dagobert SOERGEL
Department of Information Science, University at Buffalo
Buffalo, NY 14260, United States

ABSTRACT [1]

This paper compiles and organizes indexes of (1) what makes a city *smart*, (2) *Sustainability*, and (3) *Quality of Life* and examines the application of these indexes in 67 smart city initiatives around the world. There is no consensus on what it means to be a Smart City, yet many cities are adopting Smart City initiatives. Information and Communication Technologies (ICT) are the common denominator. But smart cities should evolve not only in technology but also in sustainable development (measured by UN goals and by indexes such as ISO 37.120:2014) that supports good quality of life (measured by an Urban Quality of Life (UQoL) index, such as the Human Development Index (HDI)). Measuring the *smartness* of a city requires a complex index. To determine the sub-indexes/themes and the indicators such an index should include, we analyzed seven indexes: two for *sustainability*, two for the *quality of life*, and three for *smart cities* and compared the sub-indexes/themes they include. Then we surveyed the websites of 67 smart city initiatives to see for each sub-index/theme how many smart city initiatives considered it. The themes that appeared in the highest number of indexes were also most frequent in smart city initiatives; cities tackle the same problems of society.

Keywords: Smart City, Sustainability, Quality of Life, Index.

Note on Terminology (these terms are used throughout)
An *index* is an instrument for arriving at a total score for a composite variable, such as the *Urban Quality of Life (UQoL)*. It may consist of *sub-indexes* or *themes*, such as *Quality of Housing* or *Quality of Education*, each of which contributes to the total score. A sub-index/theme, such as *Quality of Housing* consists in turn of *indicators* such as *Indoor air quality*, *Acoustic insulation*, or *Building fire safety*. To sum up: Index ⊢ Sub-index/theme ⊢ Indicator.

1. INTRODUCTION

This paper compiles and organizes indexes of (1) what makes a city *smart,* (2) *Sustainability*, and (3) *Quality of Life*, and examines the application of these indexes in 67 Smart City initiatives around the world. The concept of *Smart Cities* is based on the idea of using evolving technological devices that have access to the internet and can connect to one another through the use of tools such as IoT. The first device to receive the term *smart* was the smartphone, which is able to access the internet and expand its utilities using apps. IoT also allowed smartphones to connect to stereo systems, cars, TVs, computers, and even houses, which enabled smartphone users to lead *smart* lives. Accommodating these citizens required digital innovation (DI) in social and commercial settlements where people live and work using *smart* technologies. Combining smart devices, smart buildings, and smart lives results in Smart Cities [1][2].

Smart Cities, then, arouse from the need to apply technological advancement and digital innovation to solve social, economic, and environmental problems brought by increasing urbanization [3]. The tendency of large cities to become increasingly urbanized and the influx of young people eager to advance have placed increasing pressure on cities to accommodate these new citizens and provide all the resources they need. For example, this migration may tax a range of urban resources, such as traffic and mobility, electrical power, public safety, and public health. The population shift may also affect the economy, with the shift in emphasis from agrarian to industrial production. This trend can be observed in China, for example. In response to thes trends cities must improve their infrastructures to accommodate the qualified professionals who are needed to drive this new economy. This is a key challenge to ensure global competitiveness [4].

[1] We thank our peer editor Ali Pirzadeh not just for clarifying edits but also substantive comments important for further work. He is an economist, a consultant and educator on development economics, and author of several books, including:

Institutional Learning and Knowledge Transfer Across Epistemic Communities: New Tools of Global Governance
and *Culture, Innovation*, and *Growth Dynamics: A New Theory for the Applicability of Ideas.*

The concept *Smart City* is not uniform; it is still under construction [5]. Specialists agree that a Smart City should use information and communication technologies (ICTs) to improve its citizens' quality of life [4][6]. According to [7] Smart Cities "use information and physical technology, combined with Internet of Things, to optimize the city infrastructure and make the city more efficient and more livable". According to [4] "One working definition of a Smarter City is connecting physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city". Companies such as IBM, Siemens, and CISCO have made significant contributions to the development and definition of Smart Cities. IBM launched the project "Smarter Planet" in 2008 for "more efficient and reliable solutions of social, environmental, economic problems through the latest advances in ICT. The three main features of Smarter Planet solutions are marked III: instrumented, interconnected, and intelligent operation" [4][8].

These definitions make clear that citizens' quality of life is paramount when constructing a Smart City. However, a concern arises when Smart City initiatives focus on technology use as an end itself rather than on the ultimate goal of improving peoples quality of life. [1] examined this theme in an analysis of some smart city initiatives, such as Songdo neighborhood in South Korea and Masdar City in the United Arab Emirates, highlighting the danger of discussion shifting away from the urbanistic essence of the city to the systems engineering perspective.

It is of extreme importance, then, to search for a standardization of the concept *Smart City* through tools that allow for city decisionmakers to adopt suitable technologies that serve the ultimate purpose of improving the quality of life. This ultimate purpose is sometimes forgotten in the quest for technology. A proposal for a new index composed of a complete set of indicators grouped into meaningful sub-indexes/themes may be a way to consider both technology and its ultimate purpose, improving and maintaining quality of life.

There are two issues to keep in mind:

- We must be able to measure the success of Smart Cities' initiatives to determine what works best in which circumstances and adapt planning and implementation accordingly.
- A number of indexes are used to measure (or score) (1) city "smartness", (2) Urban Quality of Life, and (3) Sustainability. These indexes overlap heavily in the indicators they use.

Our research pursues two objectives:

1. To compile a comprehensive list of indicators from several widely used indexes and to group these indicators into themes;
2. To analyze Smart Cities' initiatives to examine the themes they address.

This paper presents first steps to achieve these goals.

2. SUSTAINABILITY

The first worldwide concept of sustainability was put forth in the Brudtland Report in 1987, by the United Nations (UN). In this report, sustainability was defined as the equilibrium between society, environment, and economy [9]. This concept has been widely accepted throughout the years and used by countries, governments, and companies to develop goals in order to achieve sustainable development.

Later, in 2000, the UN decided to set more specific goals, gathering world leaders in New York to sign the United Nations Millennium Declaration, which held countries responsible for adopting a partnership in order to end extreme poverty and other major worldwide problems by 2015. The eight goals were to:

1. Eradicate extreme poverty;
2. Achieve universal primary education;
3. Promote gender equality and empower women;
4. Reduce child mortality;
5. Improve maternal health;
6. Combat HIV/AIDS, malaria and other diseases;
7. Ensure environmental sustainability;
8. Create a global partnership for development.

Since, by 2015, these goals had not been achieved, the UN convened another summit to renew the partnership [10].At this summit, held in September of 2015, another partnership was set between world leaders, entitled the *2030 Agenda for Sustainable Development*. In this Agenda, seventeen new goals were set, derived from the 2000 goals. The new goals were:

1. No poverty;
2. Zero hunger;
3. Good health and wellbeing;
4. High-quality education;
5. Gender equality;
6. Clean water and sanitation;
7. Affordable and clean energy;
8. Decent work and economic growth;
9. The development of industry, innovation and infrastructure;
10. Reduced inequalities;
11. Sustainable cities and communities;
12. Responsible consumption and production;
13. Climate action;
14. Life below water;
15. Life on land;
16. Peace, justice, and strong institutions;
17. The formation of a partnership to achieve these goals.

Eight years from the deadline, countries are currently mobilizing to achieve those goals [11].

The International Standardization Organization (ISO) addresses sustainability in ISO 37120, *Sustainable Development of Communities*. The document was developed through an initiative involving nine cities in Brazil, Canada, Colombia, and USA, from which data to create the index were gathered. To organize the process, the Global City Indicators Facility was created at the University of Toronto, Canada. The Facility formed a network of 200+ cities sharing their knowledge and results. The Smart City Indicators and ISO 37120 overlap as well as complement each other [12].

All of these initiatives were designed to improve the quality of life of the Earth's inhabitants, as well as maintaining the planet's resources in the future.

3. QUALITY OF LIFE

The definition of quality of life has evolved through changes in society over the years. The concept involves economics, society, culture, and, since recently, the environment and its role in sustainability [13].

In the 1960s, social indexes with appropriate indicators appeared in the United States to monitor people's degree of happiness [14]. Urbanism entered the discussion in the 1970s, as cities grew and the urbanization process increased. Environmental indicators became more evident in this context. With the many problems derived from urbanization, the term *quality of life* is born, alongside with environmental quality. Later, they would become *Urban Quality of Life* (UQoL) [14]. To measure and operationalize this concept, the first index proposals appeared in the 1990s, seeking to assess how these problems played out in people's lives [15].

In 1990 the United Nations published the *Human Development Index* (HDI) , with indicators grouped into themes of health, education, and financial income, gathering data from 104 countries. HDI is still used worldwide, serving as a base for cities and countries to create their own adaptation [16].

Brazil offers an example of this local adaptation. Between 2004 and 2005, Brazilian cities created their own quality-of-life indexes to help their decision makers plan their initiatives and make budget decisions.

For this paper, we included the Urban Quality of Life Index developed by the city of Belo Horizonte (IQVU). The index is well designed, has a clear methodology, and is responsible for quantifying the availability of services from the analysis of different variables that identify the spatial distribution of different infrastructures [15]. Version 1 was developed from 1994 to 1996; it included 33 weighted indicators under 9 criteria (themes). In 2006, the index was modified to accommodate an additional criterion and three more indicators. Both indexes are available on the city's website, along with all the data used for their construction [15].

4. SMART CITIES

The concept *Smart City* has been discussed as an evolving solution to support the growth of urban areas. The population growth of urban centers is associated with problems such as the inefficiency of infrastructure and basic services and the depletion of natural resources, which compromise the quality of life of citizens.

Initially, the literature on Smart Cities referred to the application of technologies in cities. This definition is insufficient; it focuses more on technology than on the solution of cities' problems. The development of this *Smart City* concept began in 2005, when technology companies, especially Siemens, Cisco, and IBM [17], adopted complex information systems applications to integrate the various operations of cities. *Smart City* refers to the consolidation of technology-based innovations in the planning, development and operation of cities [17]. By the end of 2009, this techno-centric idea of Smart Cities was widely used in cities all over the world. [18] describes a smart city as "A city in which ICT is merged with traditional infrastructures, coordinated and integrated using new digital technologies". In 2014, [19] describes t the goal of a Smart City as making better use of public resources and increasing the quality of services offered to citizens while reducing operational and public administration costs.

All of these concepts are variations of what [20] describes as *Smart City 1.0*, which was developed at a time when cities were focused mostly on ICT, economics, and technology. These actions revolved around the promotion of digital technology in particular.

Among the first to suggest a broadening of the concept, in 2009 [6] advanced a concept of a smart city that integrates social and human capital with ICTs as well as infra-structure, to provide economic growth, with the aim of achieving higher quality of life and efficiency in resource management. In 2019, [7] defines a *smart city* as a city that uses information and physical technology, combined with the Internet of Things, to optimize the city infrastructure and make the city more efficient and more livable.

By 2020, the concept has evolved to *Smart City 2.0*, which brings a broader and more inclusive view, focusing more on Sustainability, Quality of Life, and human concerns. This concept is discussed among wider communities, including urban planners. It includes studies related to the formation of cities, the behavior and needs of people living in an urban society, and the procedures responsible for implementing the infrastructure. It calls on managers to define the feasibility of interests, resources, and investments. One view states that a city can be called *smart* when investments in human and social capital, traditional infrastructure, and modern ICT promote sustainable economic growth and high quality of life through the intelligent management of natural resources achieved through participatory governance [21].

Several factors combine to create this new view of *Smart City*

One is the development of an ecosystem that connects the variables that involve city life. Systems from different sources need to be able to collect, organize, and share data and make them interoperable. This complex system needs to be organized using a good Knowledge Organization System (KOS) and can supported by other tools [7].

Another factor is enabling interconnectedness through the Internet of Things (IoT), "a recent communication paradigm, in which the objects of everyday life are equipped with micro-controllers, transceivers for digital communication, and suitable protocol stacks that enable them to communicate with one another and with the users, becoming an integral part of the internet." Examples of IoT applications are vehicles, security cameras, monitoring systems, residence automation, health system, and traffic, among others [19].

Finally, an important tool is the use of Big Data, which is the capacity to process large amounts of data to produce information. Big Data began near the end of the 1990s due to the amount of data generated every day with the appearance of smart devices. Big Data technology is responsible for processing the data from ICTs, sensors, devices, objects, the internet, and social media [20].

Our discussion of indexes is guided by the inclusive concept of *Smart Cities 2.0*, which is summarized by [22]: "*Smart cities* as an approach to minimizing urban problems, developing a more sustainable and better city to live in, where the concept stands out as quality of life and sustainability"..

For our analysis of Smart City initiatives to determine which themes and individual indicators they address, we selected 67 cities using two rankings of smart cities:

(1) The *Top 50 Smart City Governments*, 2021 edition, developed by the *Eden Strategy Institute*, among the premier consultant companies on Business Innovation Systems. They gathered information on 235 cities world-wide self-identified as smart. They used the following criteria for ranking: Vision, Leadership, Budget, Financial Incentives, Support Programs, Talent-readiness, Smart Polices, Innovation Ecosystems, and People Centricity [23].

Since this study is based in Brazil and (1) includes few Brazilian cities, we also included

(2) *Connected Smart Cities*, 2021 edition, developed by *Urban Systems*, a Market Intelligence and Urban Planning consultancy. It covers 677 Brazilian cities with a population >=50K (48 cities >500K, 274 cities 100k-500K, and 349 cities 50K-100K. The rankings consider the major areas Smartness, Connection, and Sustainability. Scores are composed of 75 weighted indicators grouped in 11 thematic axes: Mobility, Urbanism, Environment, Technology and Innovation, Entrepreneurship, Education, Health, Safety, Energy, Governance, and Economy[24].

5. SUSTAINABILITY, QUALITY OF LIFE AND SMARTNESS OF CITIES INDEXES

Note on Terminology. An *index* is an instrument (in the sense used in the social sciences, psychology, and educational testing) for arriving at a total score for a composite variable, such as the *Urban Quality of Life (UQoL)*. An index often consists of a list of *sub-indexes* or *themes*, such *Quality of Housing* or *Quality of Education*, each of which contributes to the total score. A sub-index/theme, such as *Quality of Housing* consists in turn of *indicators* such as *Indoor air quality*, *Comfort of indoor temperature, Acoustic insulation*, or *Building fire safety*.

In light of the relationship explored above between the three pillars of sustainability and quality of life, it is important to understand the convergence of themes. We studied five indexes and their component themes to determine commonalities and provide a basis for proposing a new, more comprehensive index. We studied:

- Two indexes of sustainability, ISO 37.720:2014 and STAR.
- Two indexes of quality of life, commonly known as an Urban Quality of Life Index (UQoL); we chose the UQoL used by the city of Belo Horizonte, Minas Gerais (Brazil), called IQVU, and an index published by the European Commission.
- Three indexes of Smart Cities discussed in journal papers: Alexopoulos, 2019; Cohen, 2012; and Giffinger, 2007.

Table 1 shows these seven indexes with the major themes (sub-indexes), with a gloss defining the theme taken from the source. This gives the reader a sense of the variety of approaches and of their commonalities.

We grouped the themes from the seven indexes into 15 themes, as shown in **Table 2**, which also shows the indexes in which each theme appears. The themes that appear in multiple indexes indicate common ground.

Our ultimate goal was to compile a well-organized and comprehensive list of individual indicators from many sources, including the seven listed in Table 1. Table 2 is a first step towards this goal. Examining the seven indexes, we formulated our own themes, reusing/combining the wording from the sources. We grouped these themes into five major thematic areas to provide a better overview of the entire semantic field. We added the glosses from some of the sources, also indicating the term used in the source for the theme. Table 2 and Table 4 also show the themes in each source, supporting the comparison.

We will repeat this process at the level of individual indicators to result in a very large table to be available on the Web. If interested write to one of jv.souzat@gmail.com, rmbaracho@gmail.com, or ds@dsoergel.com).

Table 1 Indexes of Sustainability, Quality of Life, and Smartness of Cities with the themes they include

1 SUSTAINABILITY INDEXES

ISO: 37120/2014) (ABNT)

Economy – Employment/ Unemployment Rate/Business/Patent
Education – Culture Commerce and Services
Energy – Consumption/Use per capita
Environment – NO2/SO2/O3 Concentration/Noise Pollution/ Green house
Finance – Capital spending/Tax collected/ Debt Service Ratio
Fire and Emergency Response – Number of Firefighters/ Disaster/Emergency/Response Time
Governance – Voter Participation/Women employed/ Citizens' Representation/Registered Voters
Health – Average Life/ Patient Hospital/Number Nurses/ Suicide Rate
Recreation – Square meters of public indoor/outdoor recreation space per capita
Safety – Number of Police officers/Homicides/ Response Time/Violent Crime
Shelter – Number of Homeless/Households
Solid Waste – Solid waste per capita/Recycled/ Sanitary landfill/Incinerator/Burned
Telecommunication and Innovation – Number internet connections/Cell phones
Transportation – Public Transportation/Personal Automobiles/Vehicle/Transportation facilities
Urban – Jobs/Housing Ratio/Green Area/Trees Planted
Wastewater – Percentage of city population served by wastewater collection/% no treatment
Water and Sanitation – Percentage of city population with potable water supply /Improved

STAR (STAR Communities)

Built Environment – Environmental Comfort/ Public Spaces/ Housing Affordability
Climate and Energy – GHG/Industry/Resources/ Water and Waste/Energy Supply
Economy and Jobs – Business Development/ Local Economy/Workforce and Quality Jobs
Education, Arts and Community – Arts/Culture/Diversity
Equity and Empowerment – Human Justice and Rights
Health and Safety – Food/Air Quality/Emergencies
Natural Systems – Green areas and water protection

2 QUALITY OF LIFE INDEXES

IQVU – Urban Quality of Life Index (UQoL)

Supply – Supply Equipment /
Culture – Culture Commerce and Services
Education – Child Education/First Grade/Second Grade /
Sport – Public Spaces for recreation
Shelter – Shelter Quality/Shelter Safety
Urban Infrastructure – Environmental Integrity/ Electrical Energy/Pavement/Public Transportation
Urban Safety – Personal Safety/Patrimonial Safety/ Traffic Safety

European Commission (EC) (European Union)

People's Satisfaction with the city – Public transport and Spaces/Health Care/Sports and Culture/Education
People's Views about the city – **Employment/Housing/Foreigners/Safety and Services**
Environment – Air Quality/Noise/Cleanliness/ Green Spaces/Climate Change
People's Personal Situation – Life/Housing/ Financial Situation/Job Situation

3 SMART CITIY INDEXES

I1 – SMART CITIES (Charalampos Alexopoulos)

ICT Infrastructures – Free Wi-Fi in public areas/ Optical Fiber/Home Network
Environment – Air pollution Measurement Sensors/ Noise/Seismograph
Transportation Mobility – Traffic/Intelligent System/ Smart Stops/Parking spaces
Health – Health Care tele monitoring systems/Establishment of Municipal Health Center
Waste Management & Water Resources – Online Quality measurement system/Sensors
Energy/Sustainable Development – Photovoltaic Installation/Smart meters for energy consumption
Tourism/Culture – cultural Infrastructure/ Electronic local guide/App for mobiles
Economy/Development – Promoting entrepreneurship/ Innovative Actions
Security – Actions addressing citizens and protection plans and emergencies
e-Government – Electronic voting Application/ Electronic Signatures/Municipal Services online

I2 – SMART CITIES (Boyd Cohen)

Environments – Smart Buildings/Resource Management/Sustainable Urban Planning
Mobility – Efficient Transport/Multi-modal Access/ Technology Infrastructure
Government – Online Services/Infrastructure/ Open government
Economy – Entrepreneurship & Innovation/Productivity/Local and Global Connection
People – Inclusion/Education/Creativity
Living – Culture and well-being/Safety/Health

I3 – SMART CITIES (Rudolf Giffinger)

Smart Economy – Innovative spirit/ Entrepreneurship/ Economic image and trademarks/Productivity
Smart Mobility – Accessibility/ICT-infrastructure/ Sustainable, innovative and safe
Smart Environmental – Natural conditions/ Pollution/ Environmental Protection/sustainable Resources
Smart People – qualification/Flexibility/Creativity/ Participation in public life
Smart Living – Cultural facilities/Health Conditions/Safety/Education/Touristic/Social cohesion
Smart Governance – Participation in decision- making/ Public and Social Service/Transparent/Political

Table 2 – Themes for grouping indicators identified in Table 1 arranged in five thematic areas indicating the indexes in which they occur
(Analysis at the level of individual indicators is future work)

Thematic areas and themes	#	ISO	STAR	IQVU	EC	I1	I2	I3
1 Sustainable Development Smart Buildings/Resource Management/Sustainable Urban Planning (I2)	3		X		X	X		
2 Physical Infrastructure *Urban infrastructure* Environmental Integrity/ Electrical Energy/Pavement/Public Transportation (IQVU)								
2.1 Environment NO2/SO2/O3 Concentration/Noise Pollution/Green house (ISO) Air pollution Measurement Sensors/Noise/Seismograph (I1) Natural conditions/Pollution/Environmental Protection (I3) *Urban* – Jobs/Housing Ratio/Green Area/Trees Planted (ISO)	7	X	X	X	X	X	X	X
2.2 Energy Consumption/Use per capita (ISO) *Energy/Sustainable Development* – Photovoltaic Installation/ Smart meters for energy consumption (I1)	3	X		X		X		
2.3 Water Resources Management *Water and Sanitation* – Percentage of city population with potable water supply /Improved (ISO) *Waste Management & Water Resources* – Online Quality measurement system/Sensors (I1)	3	X	X			X		
2.4 Waste Management Solid Waste – Solid waste per capita/Recycled/Sanitary landfill/ Incinerator/Burned (ISO). Wastewater – Percentage of city population served by wastewater collection/% no treatment (ISO)	2	X	X			X		
2.5 Transportation and Mobility *Transportation* – Public Transportation/Personal Automobiles/Vehicle/Transportation facilities (ISO) *Transportation Mobility* – Traffic/Intelligent System/Smart Stops/ Parking spaces (I1) *Mobility* – Efficient Transport/Multi-modal Access/ Technology Infrastructure (I2) *Smart Mobility* – Accessibility/ICT-infrastructure/Sustainable, innovative and safe (I3)	6	X		X	X	X	X	X
2.6 Fire and Emergency Response Number of Firefighters/Disaster/Emergency/Response Time (ISO)	1	X						
2.7 Housing and Shelter *Shelter* – Number of Homeless/Households (ISO). *Shelter* – Shelter Quality/Shelter Safety (IQVU)	4	X	X	X	X			
2.8 ICT Infrastructure *Telecommunication and Innovation* – # internet connections/Cell phones (ISO). Free Wi-Fi in public areas/Optical Fiber/Home Network (I1)	5	X	X	X	X	X		

Table 2 – Themes for grouping indicators identified in Table 1 arranged in five thematic areas, continued								
Thematic areas and themes	#	ISO	**STAR**	IQVU	EC	I1	I2	I3
3 Life and Health								
3.1 Life *Living* – Culture and well-being/Safety/Health (I2) *Smart Living* – Cultural facilities/Health Conditions/ Safety/ Education/ Touristic/ Social cohesion (I3)	4		**X**		**X**		**X**	**X**
3.2 Health Average Life/ Patient Hospital/Number Nurse/Suicide Rate (ISO) Health Care tele monitoring systems/Establishment of Municipal Health Center (I1)	5	**X**	**X**	**X**	**X**	**X**		
3.3 Safety Number of Police officers/Homicides/Response Time/Violent Crime (ISO) *Urban Safety* – Personal Safety/Patrimonial Safety/Traffic Safety (IQVU) *Security* – Actions addressing citizens and protection plans and emergencies (I1)	5	**X**	**X**	**X**	**X**	**X**		
3.4 People Inclusion/Education/Creativity (I2) *Smart People* – Qualification/Flexibility/Creativity/Participation in public life (I3)	4		**X**		**X**		**X**	**X**
4 Society and Governance								
4.1 Governance Voter Participation/Women employed/Citizens' Representation/ Registered Voters (ISO) *Government* – Online Services/Infrastructure/Open government (I2) *Smart Governance* – Participation in decision-making/Public and Social Service/ Transparent/ Political (I3)	4	**X**			**X**		**X**	**X**
4.2 E-Government Electronic voting Application/Electronic Signatures/Municipal Services online (I1)	1					**X**		
4.3 Economy Employment/ Unemployment Rate/Business/Patent (ISO). Including *Supply* – Supply Equipment (IQVU) *Economy/Development* – Actions promoting entrepreneurship/ Innovative Actions (I1) Entrepreneurship & Innovation/Productivity/Local and Global Connection (I2) *Smart Economy* – Innovative spirit/Entrepreneurship/Economic image and trademarks/ Productivity (I3**)**	5	**X**	**X**			**X**	**X**	**X**
4.4 Finance Capital spending/Tax collected/ Debt Service Ratio (ISO)	1	**X**						
5 Education and Culture								
5.1 Education Including Child Education/First Grade/Second Grade (IQVU)	4	**X**	**X**	**X**	**X**			
5.2 Culture Culture Commerce and Services (IQVU)	4		**X**	**X**	**X**	**X**		
5.3 Recreation and Sport *Recreation* – Square meters of public indoor/outdoor recreation space per capita (ISO) *Spor*t – Public Spaces for recreation (IQVU**)**	2	**X**		**X**				
5.4 Tourism *Tourism/Culture* – Cultural Infrastructure/Electronic local guide/Mobile app (I1)	1					**X**		

6. CONVERGENCE OF THEMES ACROSS INDEXES

In light of the relationship explored above between the three pillars of smart city, sustainability, and quality of life, it is important to understand the convergence of themes across indexes. Table 3 summarizes these relationships.

- Energy, ICT and Infrastructure, Environment, Health, Safety and Mobility appeared in **5 or more** indexes; clearly these themes are convergent with the three pillars smartness, sustainability, and quality of life.
- Five themes appeared in **4** indexes: housing, culture, economy, education, water management.
- Five themes appeared in **3** indexes: e-government, waste management, governance, recreation, tourism.
- Only three themes appeared in **only 1 or 2** indexes: waste management, emergency response, finance.

Table 3 – Convergence of themes across indexes

Themes appearing in		
Seven indexes	1	Environment
Six indexes	1	Transportation and Mobility
Five indexes	4	ICT and infrastructure, Health, Safety, Economy
Four indexes	5	Housing and Shelter, Life, People, Governance, Education
Three indexes	3	Sustainable Development, Energy, Water Resources Management
Two indexes	1	Waste Management
One index	2	Emergency response , Finance

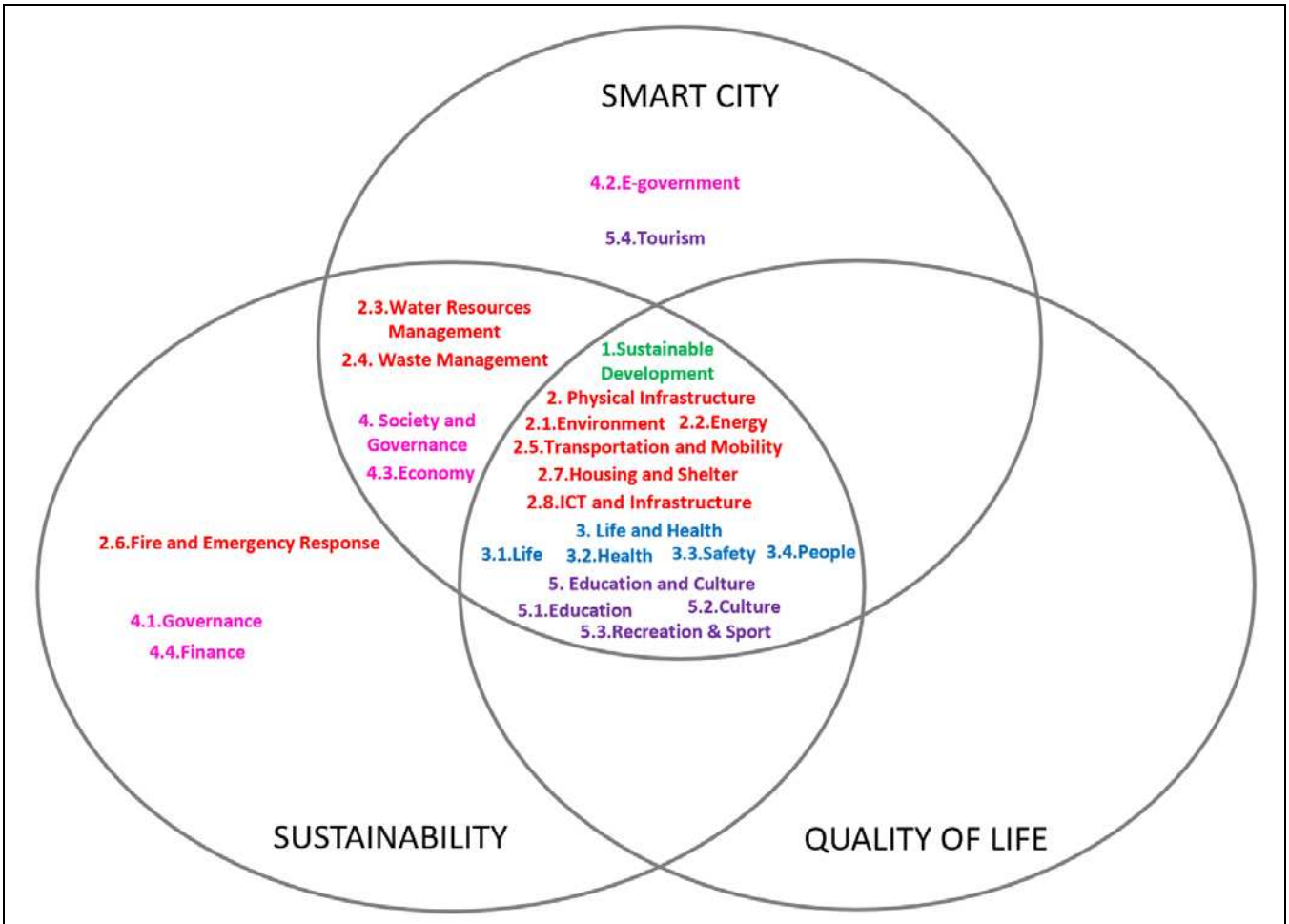

Figure 1 – Convergence of Themes across the Three Pillars Smart City, Sustainability, and Quality of Life

7. ANALYSIS OF HOW THEMES ARE ADDRESSED IN CITY INITIATIVES

To determine how the themes (and, ultimately, the individual indicators) we identified across several indexes are addressed in real-life scenarios, we identified 67 cities from two rankings of smart cities: the *Top 50 Smart City Governments* and *Connected Smart Cities* (see Section 4). We then searched for information on each city's Smart City initiatives on the city's official website and other official information sites in order to identify which of the 21 themes were addressed in each initiative. Table 4 shows for each theme the percentage of the 67 cities whose materials mention it. This provides a sense of the directions in which the cities are aiming their initiatives, and, in particular, whether they are contemplating quality of life and sustainability as factors in their development.

We found that the themes that appeared on many indexes also were addressed in many cities. Cities address themes that are involved in the three pillars of smartness, sustainability, and urban quality of life to face current problems and obtain innovative solutions. At this point, it is worth mentioning a limitation of this analysis. It is based on data from city websites, not on data about what is actually happening in cities "on the ground". This may be the reason why *Fire and Emergency Response* (42%) is at the very bottom of the list. It is clearly an area of high importance, and one that can be greatly improved by the intelligent use of data and communication technologies.

The two most prevalent themes in the city initiatives were Environment (88%) and Transportation and Mobility (87%), followed by Economy (85%) and Education (81%). The others were below 80%: Energy (78%), ICT and Infrastructure (76%), Health (73%), Culture (72%), e-government (70%), Safety (66%), Waste Management (61%), Water-Resources Management (60%), Tourism (58%), Housing and Shelter (49%), Recreation (48%), and Fire and Emergency Response (42%).

The positioning of Environment (88%) at the top of the list could be a reflection of climate change and other related factors. Waste Management and Water-Resources Management are directly related to Environment, which could explain why they were not higher up on the list.
Health and Safety were not ranked as high as expected, possibly because the cities already had well-structured systems for these themes, especially the cities located in Europe. Recreation and Tourism ranked low in both analyses. The importance of Recreation for health may not be recognized everywhere, while Tourism is not important in all cities (it may well be ranked high in a local adaptation).

The themes Life, People, and Finance came from one index and may be included under different themes in other indexes. Therefore, they were not considered in the survey.

8. CONCLUSIONS

All three pillars considered in this study are convergent when discussing the development of a city. The study of indexes that were developed from different methods but resulted in similar patterns shows that the entire world is concerned with the same criteria.

The three themes that appeared in all five of the studied indexes and were at the top of the analyzed Smart City initiatives also converged with the UN's Sustainable Development Goals. The Environment theme can be associated with SDGs 6, 7, 12, 13, 14, and 15. Mobility and ICT can be related to SDG 9.

Smart Cities 1.0 had the application of technology to improving city infrastructure and services and making cities function more efficiently as its main focus. With the advancement of applications and the deepening of the concept of the city, *Smart Cities 2.0* has focused on solving urban problems and improving the quality of live by using new technologies and improved governance involving the whole community. The term does not yet have a consensus and fluctuates among professionals from different areas, including Architecture, Engineering, Information and Communication Technology, and Urban Planning,

Sustainability concepts and Urban Quality of Life indexes converge with the theme of Smart Cities. These indexes have been measured for a long time and now aggregate the themes and individual indicators of smart cities. Sustainability and quality-of-life indexes need to be components of Smart City indexes in order for cities to develop technology that improves the quality of life of urban populations and supports sustainable development.

In this paper we have compiled and organized indexes for (1) what makes a city *smart*, (2) Sustainability, and (3) Quality of Life. We have arranged the themes from these indexes into a coherent structure, and we plan to continue this work on the more detailed level of individual indicators. Due to the sheer number of indicators and variations in their definitions, this is a substantial task, related to the idea of developing a comprehensive ontology (as used in information systems) for Smart Cities or the broader concept of *smart ecosystems*.

To ground our work in the real world, we surveyed the websites of 67 Smart City initiatives to determine for each theme how many Smart City initiatives considered it. The themes that appeared in the highest number of indexes were also the most frequent in the Smart City initiatives. Cities tackle the same social problems.

The measurement of the *smartness* of a city requires a complex index. This paper offers an initial perspective on how such a comprehensive index could be developed. The broad use of such an index would increase the comparability of data on Smart City initiatives.

Table 4. Themes appearing in City Initiatives "Pillar" refers to 1.Smart City, 2.Sustainability, 3.Quality of Life				
	% Cities	**# Pillars**	**# Indexes**	**Smart City Initiatives Examples**
1 Sustainable Development				
2 Physical Infrastructure				
2.1 Environment	88	1, 2, 3	5	Three-dimensional models to identify/prevent heat islands (Lisbon)
2.2 Energy	78	1, 2, 3	5	Solar pavement on Town Square for energy generation (Barcelona)
2.3 Water Resources Management	60	1, 2	4	Three plants of water pollution control (Philadelphia)
2.4 Waste Management	61	1, 2	3	App that indicates the nearest garbage can (NYC)
2.5 Transportation and Mobility	87	1, 2, 3	5	Digital pass system during lockdown (Moscow)
2.6 Fire and Emergency Response	42	2	2	Emergency Operation Center (Milan)
2.7 Housing and Shelter	49	1, 2, 3	4	New buildings must contain green area & solar/wind energy (NYC)
2.8 ICT & Infrastructure	76	1, 2, 3	5	Object detection kit to identify garbage on the streets (Amsterdam)
3 Life and Health				
3.1 Life	-	1, 2, 3	-	-
3.2 Health	73	1, 2, 3	5	Connected Ambulances that share health information (Milan)
3.3 Safety	66	1, 2, 3	6	Real-time monitoring of possible traffic accidents (Adelaide)
3.4 People	-	1, 2, 3	-	-
4.Society and Governance				
4.1 Governance		2		
4.2 E-government	70	1	2	Open data to government files (Copenhagen)
4.3 Economy	85	1, 2	4	Georeferencing of commercial establishments GEOHUB (LA)
4.4 Finance	-	2	-	-
5 Education and Culture				
5.1 Education	81	1, 2, 3	4	Use of ICT on schools to encourage startup creation (Beijing)
5.2 Culture	72	1, 2, 3	4	Free access to internet/video on cultural events (Porto Alegre)
5.3 Recreation & Sport	48	1, 2, 3	2	Real-time information on available spaces for activities (Lisbon)
5.4 Tourism	58	1	3	Tourist transferring through pods inside the airport (London)

The main message of this paper is:

(1) One goal is paramount, the goal of improving the quality of life while maintaining sustainability, keeping the environment clean and livable and ensuring that resources are not depleted but constantly renewed.

(2) Technology must never be an end itself but serve this goal.

We hope that by contributing to the intellectual foundations for understanding the workings of a smart city and to the development of tools for assessing the current state of a city and measuring the success in different areas we can support urban planners in pursuing this goal

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