



NETLOG 2021

International Conference on Network
Enterprises & Logistics Management

Decision-Making in Smart Cities: An Analytic Hierarchy Process Approach

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Abstract

Smart cities are systems based on aligned information and communication development models, which are used in many indicators to generate resources efficiency for the local community. Resilience is focused on investments and conditions through indicators and technologies to mitigate the risk impact or predictable harm events in urban areas. The article aims at studying a Smart City's current characteristics and how those characteristics impact the decision-making in order for the city to achieve the "Smart Status", considering the smart areas and resilience. To this end, we created a decision-making model using the Analytic Hierarchy Process method. Moreover, we adopted the Expert Choice software © to calculate the model. Our results show that infrastructure is essential for cities that intend to be considered smart. In addition, communication is the factor that most influences multicriteria decision-making. We conclude that there is a need to include the idea of resilience in the discussion that revolves around smart cities.

Keywords. smart cities, resilient city, multicriteria decision, Analytic Hierarchy Process.

Resumo

Cidades inteligentes são sistemas baseados em modelos de desenvolvimento de informação e comunicação alinhados, utilizados em diversos indicadores para gerar eficiência de recursos para a comunidade local. A resiliência está focada em investimentos e condições por meio de indicadores e tecnologias para mitigar o impacto do risco ou eventos de danos previsíveis em áreas urbanas. O artigo tem como objetivo estudar as características atuais de uma Cidade Inteligente e como essas características impactam na tomada de decisão para que a cidade alcance o "Status Inteligente", considerando as áreas inteligentes e a resiliência. Para tanto, criamos um modelo de tomada de decisão utilizando o método Analytic Hierarchy Process. Além disso, adotamos o software Expert Choice © para calcular o modelo. Nossos resultados mostram que a infraestrutura é essencial para as cidades que se pretendem serem consideradas inteligentes. Além disso, a comunicação é o fator que mais influencia a tomada de decisão do modelo multicritério. Concluí-se que é necessário incluir a ideia de resiliência na discussão que gira em torno de cidades inteligentes.

1 Introduction

The term Smart Cities (SCs) was adopted for the first time in the 1990s to describe the application of Information and Communication Technologies (ICTs) in different areas of urban spaces. Since then, science has been evolving with ups and downs, and the idea of smart cities are still an open concept

(European Smart Cities, 2015). SCs have become a buzz word and much is being written about it at this time, being most of them promotional and uncritical (Finger & Razaghi, 2017).

In this sense, a more detailed investigation about the concept SCs seems necessary (Papa et al., 2015). The term is not absolute, despite the convergence for ICTs, people (creativity, diversity, education), and institutions (politics and governance) (Nam & Pardo, 2011; Lee et al. 2013). Connecting smart drivers for the decision-making process of SCs in combination with resilience becomes a fundamental aspect to improve technology use and communication over the urban space (Batty et al., 2012).

The present article aims to study the SCs current characteristics and how those characteristics impact a city's decision-making to achieve the "Smart Status," considering the smart areas and resilience. To do so, we adopted the Analytical Hierarchy Process – AHP.

2 Literature Review

2.1 Smart City and Smart Areas

The initial dialogue on SCs is focused on themes related to the ICTs that have evolved to a holistic view, considering three main factors: technology (hardware and software infrastructure), people (creativity, diversity, education), and institutions (politics and governance) (Nam & Pardo, 2011; Lee et al., 2013).

European research from Vienna University of Technology (European Smart Cities, 2015) indicates that a smart city need to become smart first in other areas, creating a model of six components: smart economy, smart governance, smart living, smart people, smart environment and smart mobility, Figure 1. Each of these areas has important indicators, and the combination of them will determine whether the city is or not smart.

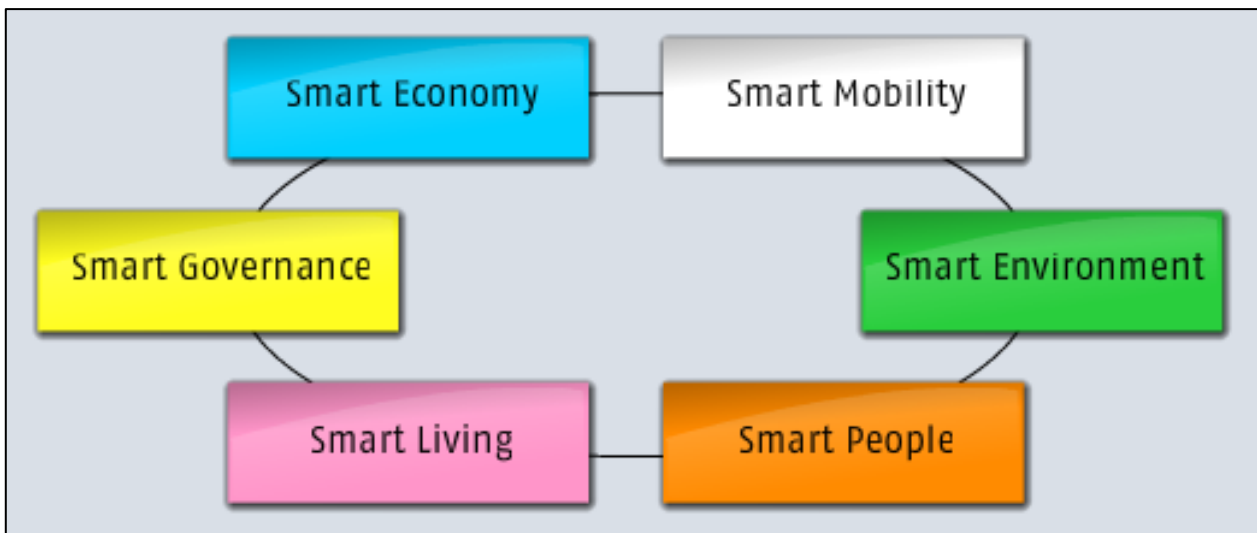


Figure 1. European Smart Cities (2015). Source: Adapted from Vienna University of Technology <http://www.smart-cities.eu/index.php?cid=-1&ver=4>

These six areas have the following indicators:

- **Smart Economy:** (1) Innovative, (2) Entrepreneurship, (3) City image, (4) Productivity, (5) Labour market, (6) International integration. Many researchers focus on the use of ICTs applied

to several functional elements of smart cities to ensure economic development and competitiveness, in this case, the characteristics of the smart economy must be separated from the digital economy. The concept of smart economy is used as an innovation economy applied mainly to industry 4.0. A smart economy entails the presence of innovation clusters (Bakici et al., 2013).

- **Smart People: (1) Education, (2) Lifelong learning, (3) Ethnic plurality, (4) Open-mindedness.** The “intelligence” of a city depends a lot on people's participation in projects. This participation engages several communication tools (such as the city portal, social networks, and smartphone applications). SCs need people to be continuously connected, especially in public places, public transport, and their homes, especially to share their experiences and knowledge. The main objective is to be more efficient in the use of natural resources and to provide a better quality of life to people. The proper maintenance of this social dimension is a challenge to be overcome (Khatoun & Zeadally, 2016).
- **Smart Environment: (1) Air quality, (2) Ecological awareness, (3) Sustainability resource management.** They are elements of the Internet of Things (IoT) which is a network of smart objects (physical or digital) within an infrastructure. This network known as the smart environment is recognized as a promising paradigm for a new generation of smart applications and services. Several important research questions about its applicability have not been sufficiently examined, especially in terms of human involvement (Stankovic, 2014).
- **Smart Mobility: (1) Local Transport System, (2) (Inter)national accessibility, (3) ICT-Infrastructure, (4) Sustainability of transport system.** The concept of smart mobility consists of the development of logistics and transport activities that use smart technology in order to reduce the negative effects of mobility, especially polluting aspects. The public and private transport system, as well as cargo transport, represents a significant portion of the mobility service support system, considered vital for cities and citizens (Czech et al., 2018).
- **Smart Governance: (1) Political awareness, (2) Public and social services, (3) Efficient and transparent administration.** Looking at the term governance, it manifests itself in two particular ways: electronic governance and smart governance. The former is defined as the power to apply digital technologies in smart activities for the processing of information and decisions while the latter is established as the applicability of technology by governments, to transform themselves, supporting interactions with customers and relationships with people, companies, other non-state entities, and other government divisions (Pereira et al., 2020).
- **Smart Living: (1) Cultural and leisure, (2) Health conditions, (3) Individual security, (4) Housing quality, (5) Education facilities, (6) Touristic attractions.** In the 1980s, the concept of smart homes simply meant the level of home automation, but since the year 2000, the idea of smart living has become quite flexible. They are continually adjusting using data from previous experiences, such as user preferences and interaction with other devices. In addition, smartphones and the internet have transformed homes with the use of smart and affordable apps, so the concept of "smart home" no longer fits, and the notion of "smart life" has emerged to represent the range of services innovators who seek to add value to tasks and routines within homes (Shieh et al., 2013).

As can be observed, the concept of SCs are complex and open to new ideas and thoughts that are built from different areas and private and public interests. Thus, to balance them in an ideal city it is necessary to meet the communication flows through available technologies, however, there several obstacles for this concept to become a reality in many countries.

A smart city can improve society's standard of living, using advances in emerging technologies such as Blockchain, Internet of Things (IoT), and Artificial Intelligence (AI). These advances bring opportunities and challenges to achieve the goals of creating these sustainable smart cities (Singh et al., 2020).

2.2 Resilience

The objective of resilience is to open the productivity of resources as indicators, having the capacity to structure and face the contradictory impulses inherent in the contested processes of recovery of urban areas (Vale & Campanella, 2005).

In this sense, a Smart Mature Resilient (SMR) is a structure for enabling stages of resilience in a city. It consists of five stages: (1) Starting (Terminal Incipient Resilience Management and Definition of resilience action plan), (2) Moderate (Towards Resilience Management and Implementation of resilience action plan), (3) Advanced (Systematization/operationalization of Resilience action plan), (4) Robust (Commitment and Involvement of The Agents Towards Resilience, Internationalization of Resilience) and (5) Vertebrate (Leading Resilience City) (Smart Mature Resilient, 2018), Figure 2.

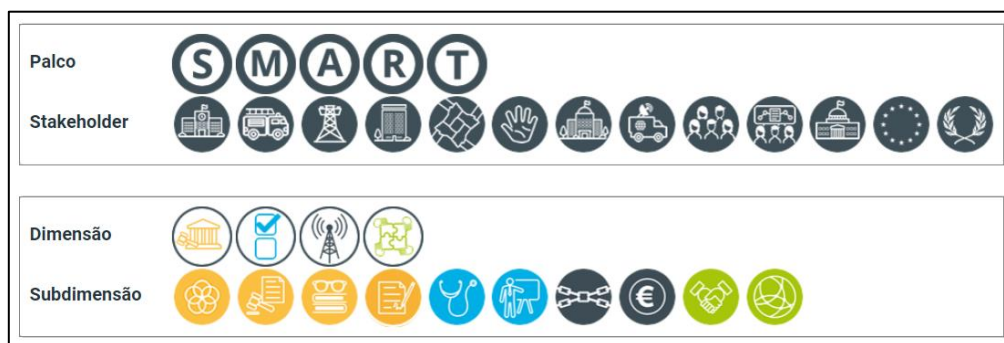


Figure 2. Smart Mature Model (2018). Source: Adapted from University of Navarra <https://smr-project.eu/home/>

A resilient city consists in validating guidelines of a resilience management that uses protective actions against natural or artificial risks, allowing society to take actions of resistance, absorption, and recovery from the effects of a risk in a timely and efficient manner. In this case, the Smart Mature Resilience (SMR) describes that urban areas evolve through stages of resilience (Smart Mature Model, 2018).

3 Materials and Methods

The definition of the problem of the research was elaborated considering the Analytic Hierarchy Process – AHP. The AHP is a multicriteria method widely adopted for decision-making developed by Tomas L. Saaty. The objective is to solve problems with the multiple criteria technique (Maleti et al., 2014).

The first step in applying AHP is to align the criteria and sub-criteria to perform a pairwise comparison using a scale of importance numbered between 1-9, where 1 is leveled with equal importance and 9 of extreme importance. The AHP converts comparisons into fractions where the weight of each element

in the decision model is established (Saaty, 2010). The comparisons consider relative weights among the criteria that must be evaluated. It only remains to calculate the statistical probability of each of the alternatives. Thus, the probability of an alternative to reaching the previously established objectives is determined (Wollmann, 2017).

A decision tree for the SCs problem was built, Figure 3. The decision tree presents the objective, criteria, and sub-criteria and indicates the alternatives.

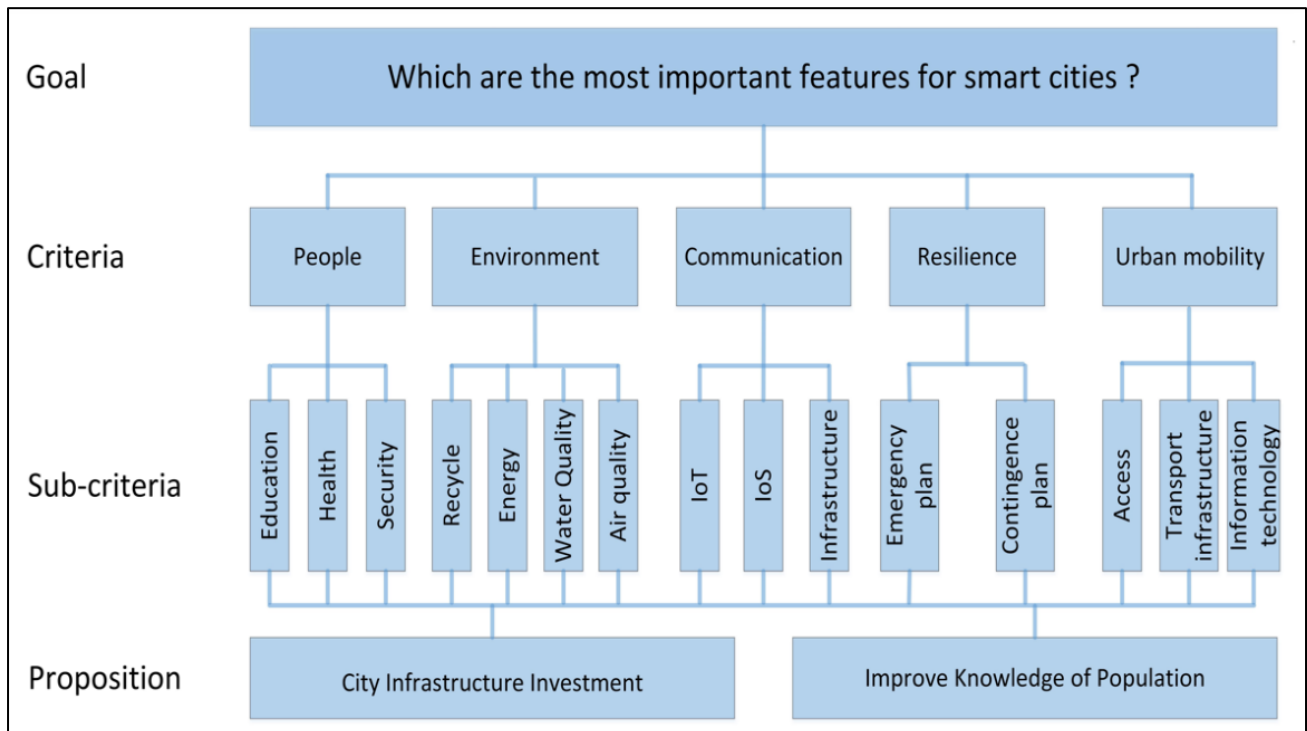


Figure 3. Decision tree. Source: Authors (2020)

Based on the literature and interviews with three experts from smart cities, city logistics, and public transportation we established the issues involved and the weight of the criteria that affect the decision-making process. The participation of specialists to judge a given theme is fundamental for the construction of the decision tree in the AHP (Reis et al., 2016). The decision model variables were calculated with Expert Choice® v.11 software.

The scientific papers that have been studied (Table 1) provide the evidence to determine the judgment between the areas and indicators of smart cities. This study is aimed at cities that make investments and the use of technology in their strategic urban planning process with the participation of citizens, catalyzing these efforts for economic development and improving the quality of life.

Table 1. Description of the literature used to assist in the assignment of criteria weights in parity comparisons.

Source	People	Environment	Communication	Resilience	Urban Mobility
Akande et al. (2019)	X	X			X
Anthopoulos et al. (2015)				X	
Arafah et al. (2018)				X	
Chourabi et al. (2012)	X	X			
Dameri (2014)	X	X	X		X
Dameri et al. (2019)	X	X			
D'Ascanio et al. (2016)				X	
Desouza & Flanery (2014)				X	
Giffinger & Gudrun (2010)	X	X	X		X
Giffinger et al. (2010)	X	X	X		X
Hernantes et al. (2019)				X	
Huovila et al. (2019)	X	X			
ISO 37120 (2018)	X	X	X		X
Lee et al. (2013)	X	X	X	X	
Lombardi et al. (2012)	X	X			
Meijeringa et al. (2014)	X	X			X
Musa, (2018)	X			X	X
Papa et al. (2015)				X	
Singh et al. (2020)		X	X	X	
Smart Mature Resilient (2018)		X	X	X	
Vale & Campanella (2005)	X	X	X	X	X
Velasquez et al. (2018)		X	X	X	
Zhu et al. (2019)		X	X	X	

Source: Authors (2020)

4 Results and Discussions

The main results are shown in Figure 4.

Communication was considered the most important criteria of SCs (0.437), followed by People (0.250), Resilience (0.139), Urban Mobility (0.118), and Environment (0.057). Based on these results we concluded that city infrastructure investment (0.564) is fundamental to establish a smart city. The results emphasize the importance of current and future discussions on investments and infrastructure improvements in SCs (Huovila et al, 2019).

In Figure 5 we can identify the performance of the alternatives for each criteria.

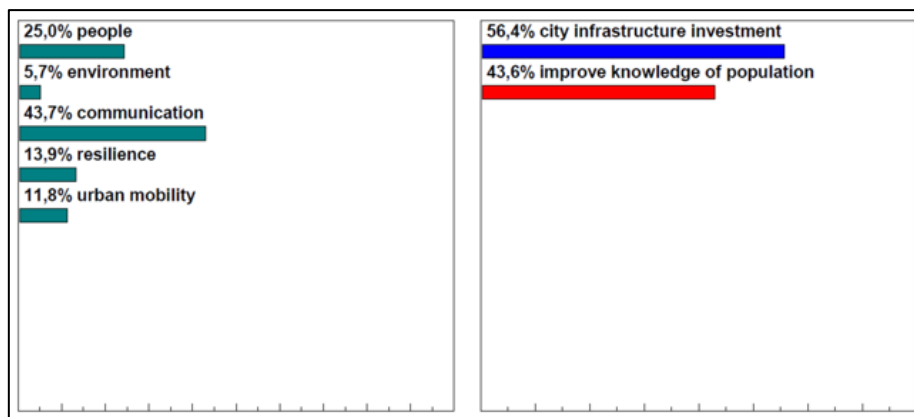


Figure 4. Performance Sensitivity Nodes by Criteria (%). Source: Authors (2020)

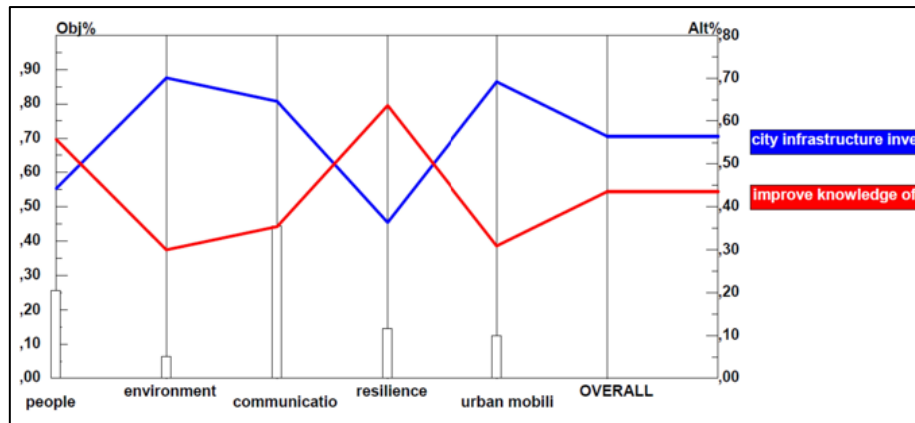


Figure 5. Performance Sensitivity Nodes by Criteria (scale). Source: Authors (2020)

The investment in the infrastructure of cities was the best approach among the five criteria. However, for resilience, the factor more relevant is improved knowledge of the population that affects the capacity of the city to recover after a crisis.

Given that our results indicated:

- Communication is the most important factor for SCs (0.437) and provides the means to enable the SCs (Dameri, 2014; Giffinger & Gundrun, 2010; Giffinger et al., 2010; ISO 37120, 2018; Lee et al., 2013; Smart Mature Resilient, 2018).
- The uneven rise of population affects the quality of life in cities (Akande et al., 2019) making the People (0.250) a factor that impacts the directly SCs. Therefore, smart cities seek to improve the use of scarce resources through electronic governance (Dameri et al., 2019).
- Resilience (0.139) seems a link between the concept of a city with better-applied resources (smart cities) and planned resources (resilient cities). A resilient city consists in validating guidelines of resilience management that uses protective actions against natural or artificial risks, allowing society to take actions of resistance, absorption, and recovery from the effects of a risk in a timely and efficient manner.
- Urban mobility (0.118) is a traditional topic in SCs not observed in this decision-model. The term has branched out into other variations of mobility (smart mobility), requiring specific future research (Giffinger et al. 2010; Akande et al. 2019).
- Environment (0.057) had a low influence in SCs based on the AHP results. The result contradicts Chourabi et al. (2012) that point out the environment as a critical factor with the same potential as the other indicators of SCs. This low influence in our model maybe is connected to the AHP method that deals with weights in an isolated way.

5 Conclusion

In this study, we conducted a multicriteria decision analysis of the impact of different criteria in the decision-making in SCs. We concluded that investments in infrastructure are fundamental for cities that are intended to reach the "Smart Status". Moreover, communication was defined as the most important criteria in SCs decision-making.

Among the areas of SCs, we included resilience considering that cities are complex systems and that all criteria or sub-criteria have their systemic importance to mitigate urban risks and challenges. Thus, associating Smart Cities with resilience is a promising theme that can be continuously explored by future research.

6. Acknowledgment

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior Brasil (CAPES) Finance Code 001.

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Cover Letter Review 1

Dear Reviewer 1!

We appreciate your valuable review contribution to the submitted paper. All of your corrections manifested by your review are corrected in Table 1:

Table 1. Corrections Reviewer 1

n	Review 1	Corrections Authors
	Introduction – first paragraph – "Smart City concept as terminology..."- It is not very clear. It is better to say concept or terminology, not SC concept as terminology.	Done.
1	Introduction – first paragraph – "...technology, always improving,"... - Science also has been evolving with ups and downs.	Done
	It lacks reference or references. Maybe a bit of criticism helps, as, according to Finger, M., & Razaghi, M. (2017). Conceptualizing "smart cities." Informatik-Spektrum, 40(1), 6-13., "Smart City has become a buzzword," and "Much is being written about smart cities as we speak, most of it promotional and uncritical."	Introduction: Added the quote (Finger and Razeghi, 2017) in the third sentence of the first paragraph.
2	Introduction – second paragraph – There are two questions here. Where are the answers?	We decided to remove the questions that was not fitting in the context.
3	Introduction – fourth paragraph – The sentence "In addition to the resilient component added to SC..." alone means nothing and should be linked to the central paragraph's idea.	Excluded the sentence
4	Introduction – fifth paragraph – The article's objective should be rephrased. It is suggested: "The article aims to study a Smart City's current characteristics and how those characteristics impact a city's decision-making to achieve the "Smart Status," considering the added concept of a resilient city."	Done.
5	Introduction – fifth paragraph – What is the definition of "Smart Status?" It lacks reference or references.	Done.
6	Introduction – sixth paragraph – Verb tense coherency. It is recommendable to maintain the present tense regarding the methodology's description and its application. "Expert Choice® software is applied," instead of "was used."	Done.
7	Subitem 2.1 – first paragraph – present continuous – ...technologies have evolved... indicating that an action or condition is happening now, frequently, and may continue (into the future).	Subitem 2.1: Corrected for the suggested tense
8	• Subitem 2.1. – the last paragraph on page 3 – The paragraph should be rephrased because concepts do not depend on conditions; are defined as abstract ideas or general notions that occur in the mind, speech, or thought; they are understood to be the fundamental building blocks of thoughts and beliefs; they play an essential role in all aspects of cognition. A question: How a concept, something without a material basis, could take off? Besides, the mention of Brazil without reference or references is unclear. The possible misunderstanding here refers to the mix-up between concept and model.	Done.
9	• Subitem 2.1. – first paragraph on page 4 – This model... What model? The European Smart Cities' model? It is recommendable to begin the first sentence, to clarify it, with "The European Smart Cities' model, previously described in six areas, is very well accepted by academia (well-accepted generally considered as true or correct)...". In the last sentence, the idea of "...capable of resisting the environment and history for a long period" means sustainability or resilience?	Done.
10	• Subitem 2.2. – Figure 2 – All terms should be in English. In the acronym S M A R T, S stands for Starting, M for Moderate, A for Advanced, R for Robust, and T for Vertebrate?	Subitem 2.2 - In figure 2 it is correct as the reference. T is vertebrate.
11	• Subitem 2.2. – second paragraph – the sentence "Technological transformation is an option that governments can count on to mitigate many of the risks and	Removed.

	challenges they face in resilient cities," in addition to being repeated in the second and third paragraphs, needs to be rewritten. Perhaps the expression technological transformation puts in the plural, and the article "the" improves its understanding. It is recommended to remove the mentioned sentence from the third paragraph.	
12	• Subitem 2.2. – third paragraph – missing or wrong spaces between "Artificial Intelligence (AI)" and "these advances..."; "(Sing et al., 2020)" and "A new structure..."	Fixed.
13	Subitem 2.2. – first paragraph on page 5 – The whole paragraph should be rewritten. What is the meaning of the sentence "The objective of an RC must be open to productivity..."? The objectives do not have life, nor self-will. So, in the establishment of objectives, it must be or should be considered, or taken into consideration, or taken into account, for example, elements of "productivity," or regarded as linked to "productivity."	We reviewed for clarity.
14	• Material and Methods – first paragraph – It should be rephrased. It is mentioned research (which?), interviews (which?). In Table 1, the fifth column is Resilience instead of Resilient?	Done.
15	• Material and Methods – second paragraph – ...software is applied... is better than "...software was used..."	Materials and Methods: Corrected the tense of the second paragraph.
16	• Material and Methods – first paragraph on page 6 – to be coherent with the previous paragraph, it is recommended to change "statement" by "step."	Done.
17	• Material and Methods – second paragraph on page 6 – lack of clarification. It should be better explained and occasionally rephrased. Which "scientific papers that have been studied..."?	We reviewed for clarity.
18	• Material and Methods – third paragraph on page 6 – Dimension is like criteria in the context? In some cases, in scientific texts, synonyms to name the same word produce misunderstandings.	Excluded.
19	• Results and Discussions – first paragraph on page 6 – Is Resilience, not Resilient? Space excess in the third line.	Done.
20	• Subitem 4.1. – first paragraph on page 7 – Is resilient (element), not resilience? The last sentence came out of nowhere. It should be explained.	Done.
21	• Subitem 4.1.3. – Resilience or Resilient? – In the fifth line, it is resilient city, not resilience city?	Done.
22	• Subitem 4.1.4. – in the fifth and Sixth lines – Is better to say public transportation instead of "modes of transport of mass passengers" and freight transport instead of "transport of cargo."	Excluded and rewritten
23	• Conclusions – first paragraph – It is inconsistent with the objective. The authors should consider rephrasing it.	Conclusions: The section has been rewritten in alignment with the general objective.
24	• Conclusions – second paragraph – Confusing. It deserves an English review.	Done.
25	• Conclusions – third paragraph – "...it is observed that there are times when..." The authors should consider rewriting the whole paragraph.	Done.
26	• References – Instead of United Nations (2014), the authors should consider replacing it with a newer version: United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Highlights. ST/ESA/SER.A/423. Retrieved from < https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf >.	Citation and reference excluded

Source: Authors (2020).

Cover Letter Review 2

Dear Reviewer 2!

We appreciate your valuable review contribution to the submitted paper. All of your corrections manifested by your review are corrected in Table 2:

Table 2. Corrections Reviewer 2.

Chapters	Review 2	Corrections Authors
2	In Chapter 2: Literature Review • In Figures 1 and 2, the authors did not insert the respective sources;	Added source as recommended.
3	In Chapter 3: Methodology • In table 1, the authors did not insert the source; • In Figure 3, the authors did not insert the source; • In the methodology, it is not clear how many specialists were consulted to carry out the study; • It remains to describe which cities this study is aimed at, given that the cultural, economic and social reality of different cities can influence the perception of specialists;	Added source as recommended; Section 3 of the fourth paragraph are teams of experts interviewed for use in AHP; * Written the text for which the city profile is directed to the research in the fifth paragraph.
4	In Chapter 4: Results and Discussion • In Figures 4 and 5, the authors did not insert the source;	Added source as recommended.

Source: Authors (2020).