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THE QUADRUPLE HELIX MODEL AS A SMART CITY DESIGN PRINCIPLE

Aleksandra Kuzior and Paulina Kuzior

Abstract. The article presents considerations on the quadruple helix model as a principle of smart city design in which technological and social innovations result from cooperation and seeking synergies among four groups of stakeholders: administration, business, science and residents. The overriding goal of this synergy should be to improve the quality of residents' life in various dimensions of their individual and socio-professional functioning. An optimal model of urban management and creation of a Smart City and a Smart Sustainable City is based on knowledge, properly disseminated and distributed, as a condition for acquiring interdisciplinary competences. The cities develop for their inhabitants, without whom they become empty and die. Therefore, a holistic model of managing a Smart City should be adopted, aiming at shaping a Smart Sustainable City on this basis, i.e. taking such management solutions that do not exclude any group of stakeholders and any urban system or subsystem bearing in mind the environment and future generations. In the article the authors present selected solutions for creating Smart Cities and Smart Sustainable Cities based on the top-down model and bottom-up model, recognizing, at the same time, that well-designed synergy among the entities of the quadruple helix is based on knowledge and its proper dissemination and distribution.

***Keywords*:** Smart City, Smart Sustainable City, Quadruple Helix Model, top-down model, bottom-up model, knowledge, participatory management

JEL Classification: A14, I2, J24, O33

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1. Introduction

The issues concerning a Smart City have been widely discussed both in scientific literature and journalism for a long time. However, this concept is not such an easy task to implement into urban reality. Although various reports contain lists of 'smart cities', they vary according to the research methodology adopted, factors and indicators included in the research, comprehensiveness of studies, assessment criteria applied, etc. For example, the EasyPark's Smart Cities Index 2019 mainly emphasizes the use of technology for creating smart cities, considering digitalization as a tool for improving the quality of life. EasyPark selected five hundred cities from different parts of the globe for research. The cities held medium and high positions in the UN Human Development Index, the UN prosperity list and the European Commission's Digital City Index. The analysis included the following factors: transport and mobility, sustainability, governance, innovative economy, digitalization, living standard and expert perception. According to those studies, the top ten smart cities are rated as follows: Oslo (Norway), Bergen (Norway), Amsterdam (Netherlands), Copenhagen (Denmark), Stockholm (Sweden), Montreal (Canada), Vienna (Austria), Odense (Denmark), Singapore (Singapore), Boston (USA) (EASYPARK, 2019). In turn, the "IESE Cities in Motion Index 2019" puts more focus on human, social and managerial aspects. In the sixth edition of the studies, the researchers included a total of ninety-six indicators reflecting both objective and subjective factors, which makes the image of the examined cities more comprehensive. The indicators were grouped into nine categories:

1) Human Capital Indicators.
2) Social Cohesion Indicators
3) Economic Indicators.
4) Governance Indicators.
5) Environmental Indicators.
6) Mobility and Transportation Indicators.
7) Urban Planning Indicators.
8) International Outreach Indicators.
9) Technology Indicators.

The research was conducted in one hundred and seventy-four cities in eighty countries worldwide, with London (the United Kingdom), New York (the USA), Amsterdam (the Netherlands), Paris (France), Reykjavík (Iceland), Tokyo (Japan), Singapore (Singapore), Copenhagen (Denmark), Berlin (Germany), and Vienna (Austria) listed as the top ten (IESE Business School University of Navarra, 2019). Despite the fact that there are cities that appear in both of the aforementioned rankings (4/10), it is apparent at the first glance that these rankings are fundamentally different. Considering the subject matter taken, the latter report, referred to above, better corresponds to the considerations presented in this article, as the authors of the report, focusing on the concept of smart city management, are confident that the cooperation of science, business, public sector and civil society as the agents of change is indispensable. Based on those research approaches, it is possible to distinguish between two categories of cities described in the relevant literature: a Smart City and a Smart Sustainable City.

In the opinion of the authors of this article, the quadruple helix model is closer to the second category.

2. Literature review

The issues related to smart cities became the subject of scientific studies in the 1990s. They reflected urban development associated with the use of modern technologies, innovation and globalization (Gibson et al., 1992). The term a Smart City is also associated with the Smart Growth movement, which, since the late 1990s, has been systematically emphasizing better urban planning for improving quality of life (Harrison & Donnelly, 2011).

In 2007, William J. Mitchell, Professor of Architecture and Media Arts and Sciences at the Massachusetts Institute of Technology, in the opening lecture for the academic year 2007/2008 at the Universitat Oberta de Catalunya (UOC), defined "intelligent cities" as the areas that function based on the combination of increasingly effective digital telecommunication networks (compared to nerves), widespread intelligence (compared to brains), sensors and markers (compared to sensory organs) and software (compared to the knowledge and cognitive competences). An important feature of smart cities is the skilful combination of a new dimension with the systems that have been functioning on their territory so far. These are mechanical and electrical systems and subsystems in buildings, household appliances systems, transport systems, electrical networks, production machinery, processing plants, water supply and sewage collection networks and systems ensuring the security of inhabitants. Professor W. J. Mitchell also stated then that we are only ploughing our way towards the new intelligence of cities (Mitchell, 2007). The idea of a Smart City has become popularised thanks to researchers from the Vienna University of Technology, who presented a report on intelligent cities in the same year (Giffinger et al., 2007). This report outlined six perspectives that are commonly regarded as describing the Smart City concept (smart economy, smart mobility, smart environment, smart people, smart living, smart governance).

Currently, a Smart City and a Smart Sustainable City are discussed in many scientific studies exploring different aspects of their development: economic, financial, ecological, social, cultural, urban and architectural. Researchers focus on the challenges faced by large metropolises and design visions of cities that use modern and human-friendly technologies. The Google Scholar's database contains 2,620,000 scientific articles presenting various Smart-City-related issues (Google Scholar, 2020a), including 587,000 questions related to a Smart Sustainable City (Google Scholar, 2020b).

The specificity of particular developmental stages of intelligent cities made it possible to distinguish between three generations of a Smart City. Smart City 1.0 is an implication of technological solutions offered by technology providers - i.e. IT companies, without a proper understanding of the impact they have on the inhabitants' lives quality. Smart City 2.0 is a change of the implementation direction - the cities, or actually their administrators (governors) started to implement innovative technologies aimed at improving the inhabitants' and tourists'

quality of life. Smart City 3.0 is characterized by a new approach to citizens. They become creators of development, and the local authorities create the right conditions for their activity while encouraging the use of innovative technologies. According to B. Cohen, the author of the aforementioned classification, Smart City 3.0 has been developing since 2015. Although the phenomenon is not very common, in Cohen's opinion, the most advisable scenario for the Smart City development is to combine the properties of Smart City 2.0 with the use of the inhabitants' innovative potential, that is the evolution towards Smart City 3.0, in which the cities' administrators will treat citizens not as service recipients or customers, but as fully-fledged participants in creating jointly the better quality of life (Cohen, 2015). The principle of designing a Smart City 3.0 may be the Quadruple Helix model of Carayannis & Campbell (2009), in which technological and social innovations result, in general, from the cooperation and search for synergies among four stakeholder groups: administration (local government, government), business, science and society.

The starting point for developing the quadruple helix model was the Triple Helix model of Leydesdorff and Etzkowitz, which is based on cooperation among science, business and government (Etzkowitz & Leydesdorff, 2000). Extending the model developed by H. Etzkowitz and L. Leydesdorff with the fourth element, Carayannis and Campbell drew attention to the important role of civil society. This society is based on the media and culture together with their values, traditions and visions, as well as knowledge creation and processing (Carayannis & Campbell, 2009). In 2010, Carayannis and Campbell, based on the Triple Helix and Quadruple Helix, proposed the Quintuple Helix model (Carayannis & Campbell, 2010). Knowledge, which is supposed to lead to more sustainable development, is a driving force for progress in this model. Interdisciplinary and transdisciplinary knowledge creation is crucial here, taking into account all scientific disciplines, starting from natural sciences through humanities to social sciences. The fifth element of the model in question is the natural environment (Carayannis et al., 2012). For the purposes of this article, the authors refer to the Quadruple Helix model, mainly because they prefer a subjective approach to issues related to sustainable urban development. Each of the Quadruple Helix elements includes this human subjectivity (scientist, student, businessman, administrator, member of society, including civil society). Knowledge generated and processed at universities results from the human potential and creativity. Development of the economy, industry, and business also requires efficiency and creativity of a person equipped with appropriate knowledge, because knowledge generates innovation, which in turn brings development. This could not happen without a person. State or local government administration do not only mean regulations and procedures but also particular individuals who establish them, while society is a set of individuals who are more or less involved in co-management and co-creation of better living conditions on a local or global scale. The level of commitment depends on the quality of human and social capital. The environment does not generate knowledge and cannot be treated as subjective in this sense. Instead, it can and does serve as a source of inspiration for undertaking new research tasks and discovering new relationships and getting feedback. The environment, or more precisely natural environment, (there are few environmental enclaves on the globe, most of them are already transformed by human activity to some extent, and traces of human interference and increased anthropopressure strongly limit the natural space) is, however, primarily "oíkos",

which is the home without which man cannot survive. For the purpose of describing a strongly urbanized municipal space, it would not be possible to use a category of natural environment. However, it should be born in mind that urban development poses a number of threats to this environment, and thus to the man himself, as well as to communities. For this reason, the authors will refer to these issues, although in a different perspective than presented by the Quintuple Helix model.

3. Methods

The article uses critical analysis as a basis for the scientific research process. Moreover, it applies deductive thinking, conceptual methods and scientific modelling that allows conceptualization and visualization of the presented issues. The authors refer to the Carayannis and Campbell Quadruple Helix model, which is a starting point for further considerations and design of knowledge spreading and distribution models, which, according to the authors, is of key importance in the Smart City and Smart Sustainable City design. Referring to the top-down model and bottom-up model, the authors point to an important element related to social participation in city management, thus preferring the bottom-up model in the Smart City and Smart Sustainable City design. The bottom-up model may work well in communities well-prepared for the city co-management. Hence, the important role is assigned to institutions that create, disseminate and distribute knowledge.

4. Results and Discussion

A Smart City cannot develop without its greatest asset - people as beneficiaries and, simultaneously, agents of change. For this reason, the authors prefer a bottom-up model of creating a Smart City and taking into account the society's adequate preparedness to participate in management. Human and social capital is of utmost significance in shaping Smart Sustainable Cities (SSC) (Kuzior & Sobotka, 2019), which are to contribute to satisfying the needs of the present city inhabitants, including also development needs of future generations (Höjer & Wangel, 2014). Cooperation and searching for synergies among the four stakeholder groups, namely administration, business, science and inhabitants/citizens, are of fundamental importance for developing modern intelligent cities. This also creates space for implementing a participatory Technology Assessment model (Lakhno et al., 2018). Indeed, innovative technologies are intended to serve a man and communities to improve the quality of life of present and future generations, since the life quality is a central category of sustainable development (Kuzior, 2014). In this sense, a Smart Sustainable City should be defined as an organization "whose activities are guided by the principles of responsibility, precaution, prophylaxis, prevention and optimization in three dimensions: social, environmental and economic" (Kuzior, 2013). Those dimensions interpenetrate into and condition each other.

We will start with the Quadruple Helix model, which is the basis for further considerations in this article and is shown in *Fig. 1*.

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The aforementioned model of Carayannis and Campbell, which is based on “Triple Helix” developed by Etzkowitz and Leydesdorff (tripartite cooperation among universities, industry and state, including hybrid networks), establishes the fourth helix known as "media-based and culture-based public" (Carayannis & Campbell, 2009).

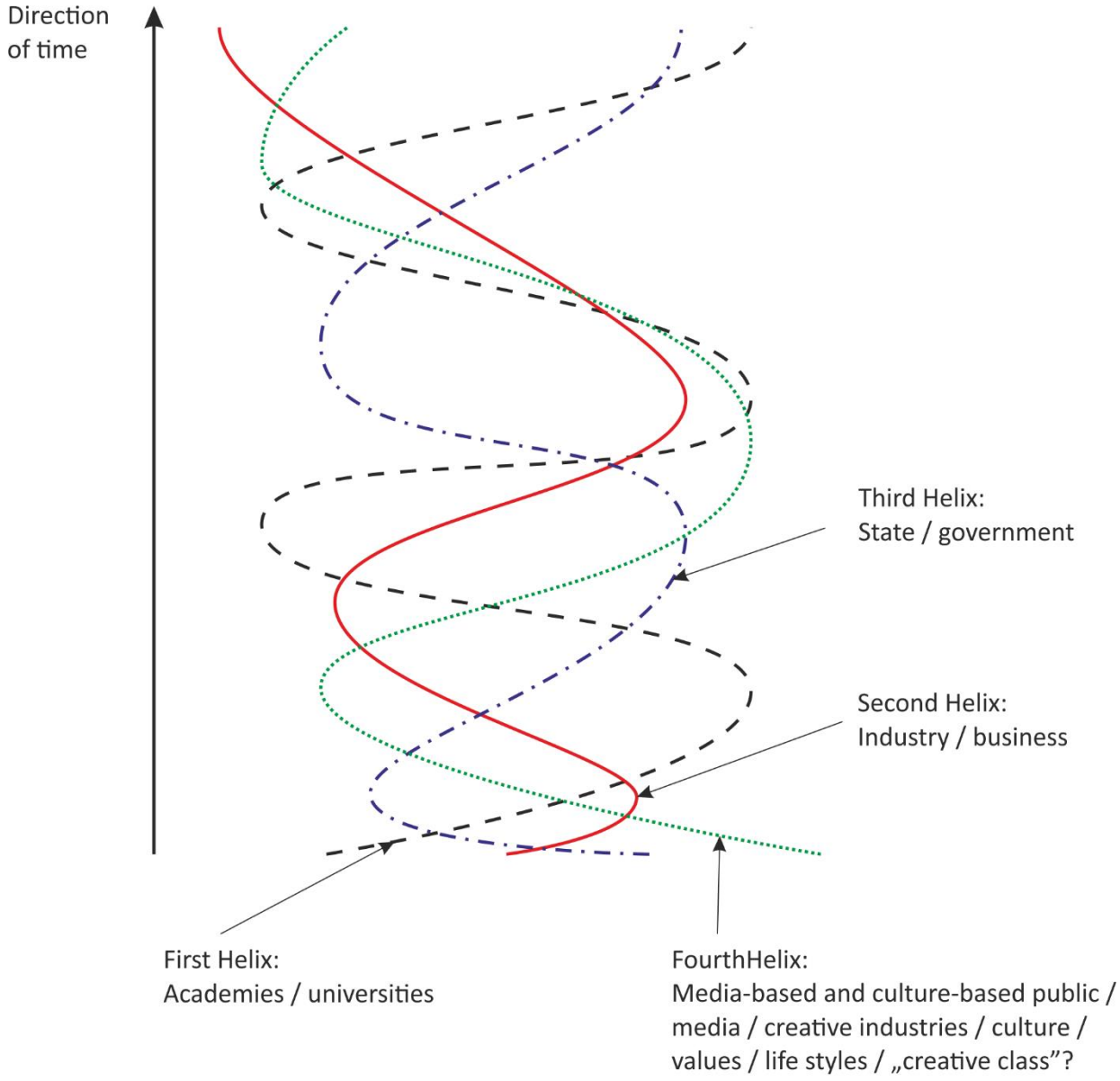

Figure 1. The Quadruple Helix Model
Source: produced by the authors based on (Carayannis & Campbell, 2009).

The media plays a significant role in this model, although, according to the authors, it should be perceived as a tool for communicating and supporting public discourse, provided that it fulfils its role properly, providing reliable, objective information, and to some extent, it is a channel of knowledge distribution (although educational institutions - universities, academies, schools - are more appropriate for knowledge dissemination). Moreover, it is considered that the expertise is crucial for designing a Smart City and a Smart Sustainable City in both the top-down and bottom-up models. Those models will be explained later in this article.

As mentioned before, knowledge is of fundamental importance for development. The concept of knowledge is very broad-ranging and defined differently by various scientific disciplines. The classical (philosophical) understanding of knowledge refers to Plato's considerations and his belief in the existence of true knowledge acquired through mental cognition (reasoning, deduction). In psychology, knowledge is defined as the contents established in mind and recorded in long-term memory. In economics, it is treated as information supporting decision-making processes and as a commodity that can be sold or bought. In sociology, both scientific and common knowledge belong to the area of social awareness. Our deliberations assume that universities, technical colleges and research institutes are the creators of knowledge, in the sociological sense of scientific expertise. This is where knowledge is created and processed, interpreted and reinterpreted, stored and distributed, as well as commercialized. The expertise accumulated in studies, passed on from generation to generation, constituting the cultural heritage of mankind, developed over many generations, enables further human development. The 1980s have brought a new understanding of knowledge. Many studies on the knowledge-based economy and society, knowledge management and learning organizations have emerged. It is enough to mention such authors as Baruk (2006), Batorski (1998), Evans (2005), Gladstone (2004), Jashapara (2006), Maier (2001), Sarvay (1999), Soo et al. (2002). Therefore, it should be emphasized once again that knowledge constitutes the foundation of development, and the accumulated experience enables the discovery of new dependencies determining growth.

If one were to imagine a concentric (centrifugal) system, knowledge would be in the middle, as a foundation for all decisions, actions and activities of people in business, government and self-government administration as well as in society (for the following analyses, the authors applied a slightly modified arrangement of categories used in the Quadruple Helix model of Carayannis & Campbell). Nevertheless, such an assumption is only possible in an ideal model. In social reality, often only groups or individuals who are privileged in certain respects (intellectual, social status and availability of education, etc.) have access to sufficient knowledge resources for their optimal development are shown in *Fig. 2*.

The concentric pattern of knowledge dissemination and distribution indicates that that knowledge is rationed for various reasons, often commercial. The greatest amount of knowledge is used by the economy and business, which in this case drives innovation, and society receives the finished product or service for thoughtless consumption. On the one hand, the government and local administration are consumers of the innovations generated that way, while on the other hand, they establish the framework of legislation, requirements and

control procedures. The least amount of knowledge (mainly expertise that can be commercialized) reaches the public. This arrangement strongly limits the formation of a civil society, which, by using its expertise and experience, could also take over a part of responsibility for development, signalling people's development needs and priorities bottom-up.

Figure 2. The Concentric Model of Knowledge Dissemination and Distribution in Free Market Economy
Source: the authors' own elaboration.

The above scheme illustrates knowledge dissemination and distribution in the free market economy. In a centrally planned economy, the arrangement of individual institutional, business and social agents would be slightly different. Such an arrangement and distribution of decision-making powers that does not allow for local governments and civil society is shown in *Fig. 3.*

Figure 3. The Concentric Model of Knowledge Dissemination and Distribution in the Controlled Economy.
Source: the authors' own elaboration.

Conversely, in a regulated market economy, the influence and decision-making powers of the government and business interpenetrate and condition each other as shown in *Fig. 4.*

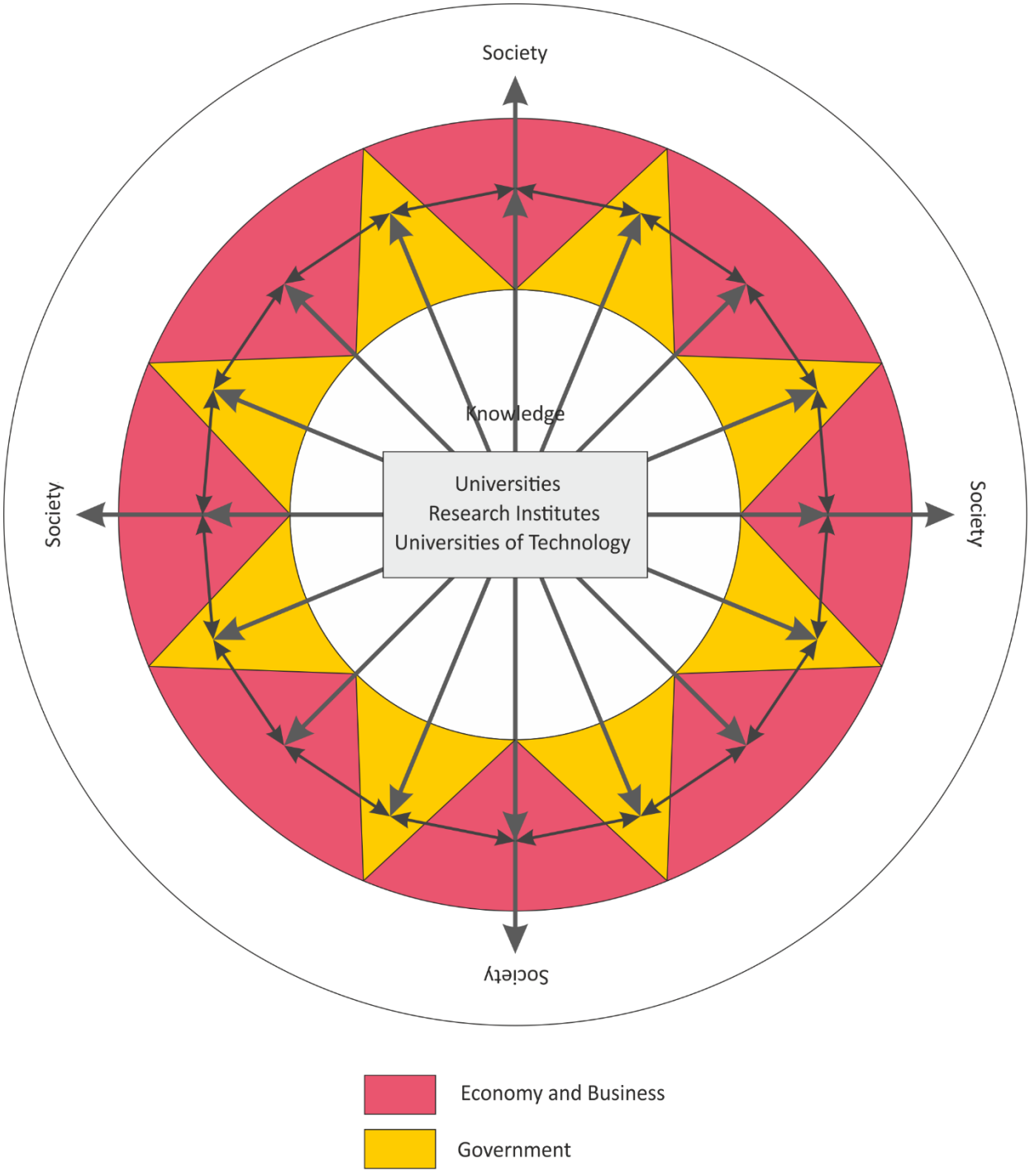

Figure 4. The Concentric Model of Knowledge Dissemination and Distribution in the Regulated Market Economy
Source: own elaboration.

When planning a Smart City and a Smart Sustainable City, the concentric (centrifugal and centripetal) knowledge model must include feedback and two-way information flows that can be generated as knowledge and innovation, as shown *in Fig. 5.*

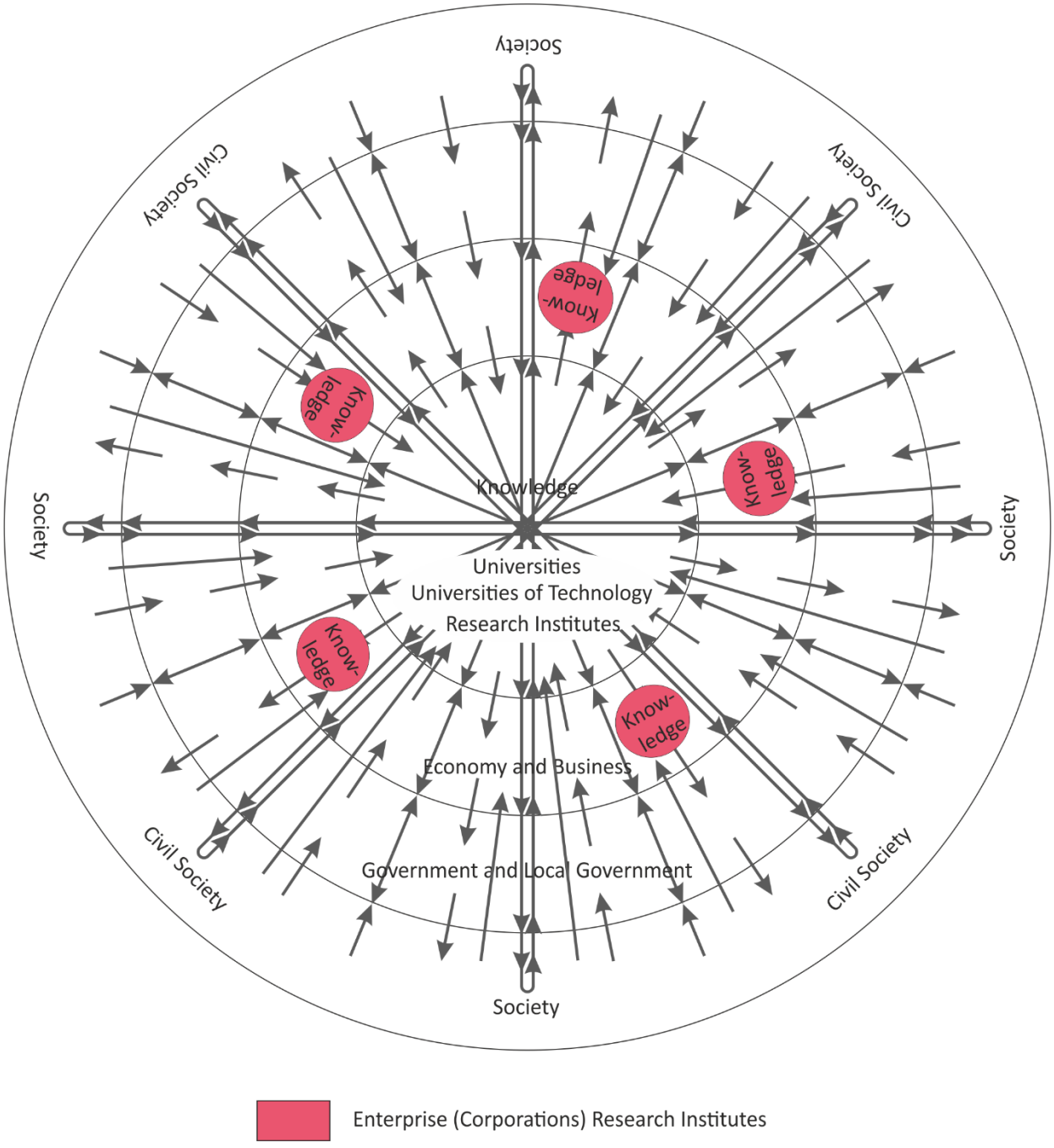

Figure 5. The Concentric Model of Knowledge Dissemination and Distribution in Planning a Smart Sustainable City
Source: the authors' own elaboration.

According to the above model, knowledge generation is not only the domain of universities or their research institutes. Scientific and economic practice suggests that research institutes tend to be set up more and more often with companies or corporations, although their establishment is limited by the internal regulations of individual countries. For example, in Poland, the establishment of research institutes is regulated by the Act on research institutes.

In principle, "a research institute, within the meaning of the Act, shall be understood as a state organizational unit, legally, organisationally, economically and financially separate, which conducts scientific research and development works aimed at implementation and application in practice thereof, (...)" (ISAP, 2010). Nevertheless, pursuant to Article 12 of the aforementioned act, it provides for the possibility of commercialization or indirect privatization of an institute. Research laboratories are also established at enterprises.

The most important assumption of the model is a two-way information and knowledge flow and feedback, at the interface of which unexpected creative solutions may appear.

The flow of knowledge can be linear and non-linear, fragmented among the individual interaction agents.

However, if one were to adopt a non-concentric system of knowledge dissemination and distribution, analyzing a small section - 1/8 of the aforementioned models - it would be easy to notice that knowledge reaches only a part of society, and it should be assumed that its distribution is selective. The authors are convinced that this model better illustrates the social reality in most countries of the world. The areas of ignorance are relatively extensive, especially in the society, as shown in *Fig. 6.*

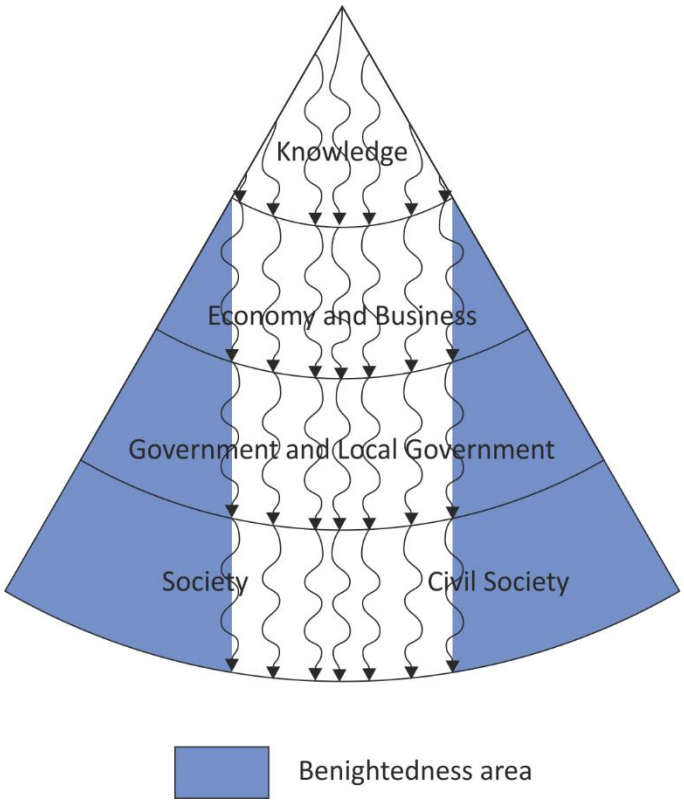

Figure 6. The Model of Knowledge Dissemination and Distribution Top-Down and Benightedness Areas
Source: the authors' own elaboration.

If we assume that there are feedback and two-way information flows, then still only a part of the population could actively provide return information. As in the aforementioned example, the areas of ignorance are quite significant, and therefore society is not sufficiently well prepared to participate in managing a Smart City and a Smart Sustainable City, as shown in *Fig. 7.*

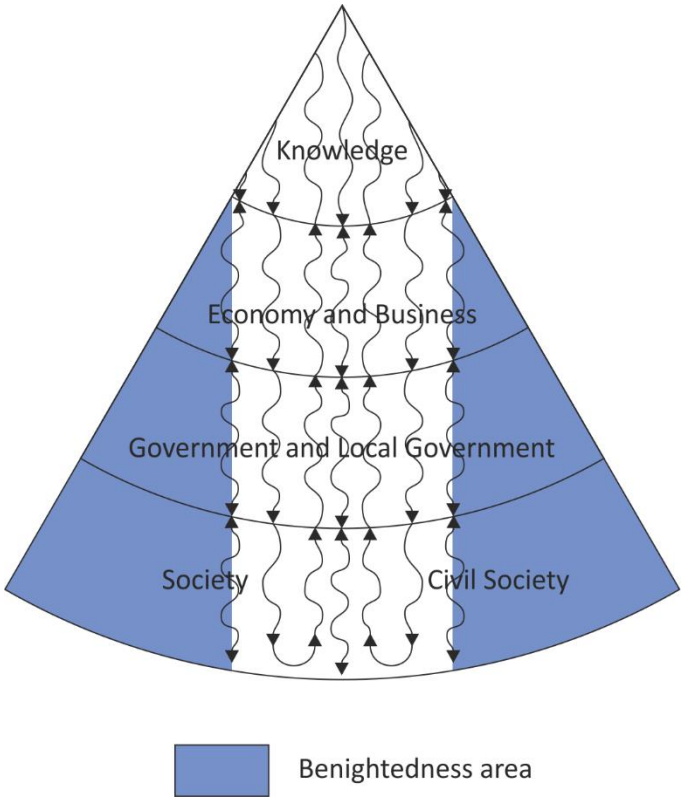

Figure 7. The Model of Knowledge Dissemination and Distribution - Feedback Loops and Benightedness Areas
Source: the authors' own elaboration.

Underdeveloped competences (competences also include specific knowledge resources of individuals) of society do not allow, or allow only selectively and with great difficulty, applying the bottom-up model of urban design and management.

The bottom-up approach, as regards planning and expansion of intelligent cities, indicates an important aspect of different stakeholders' participation in urban management and planning strategies for its development. The top-down approach defines and implements the development strategy either by central authorities (Sanseverino et al., 2018), or by local governments, based on central guidelines or local strategies prepared without involving the local community. In Poland, in some cases, a dialogue with the public is used in the form of public consultations, whose scope is regulated by the law. However, obligatory consultations are carried out in formal and administrative matters, as shown in *Fig. 8.*

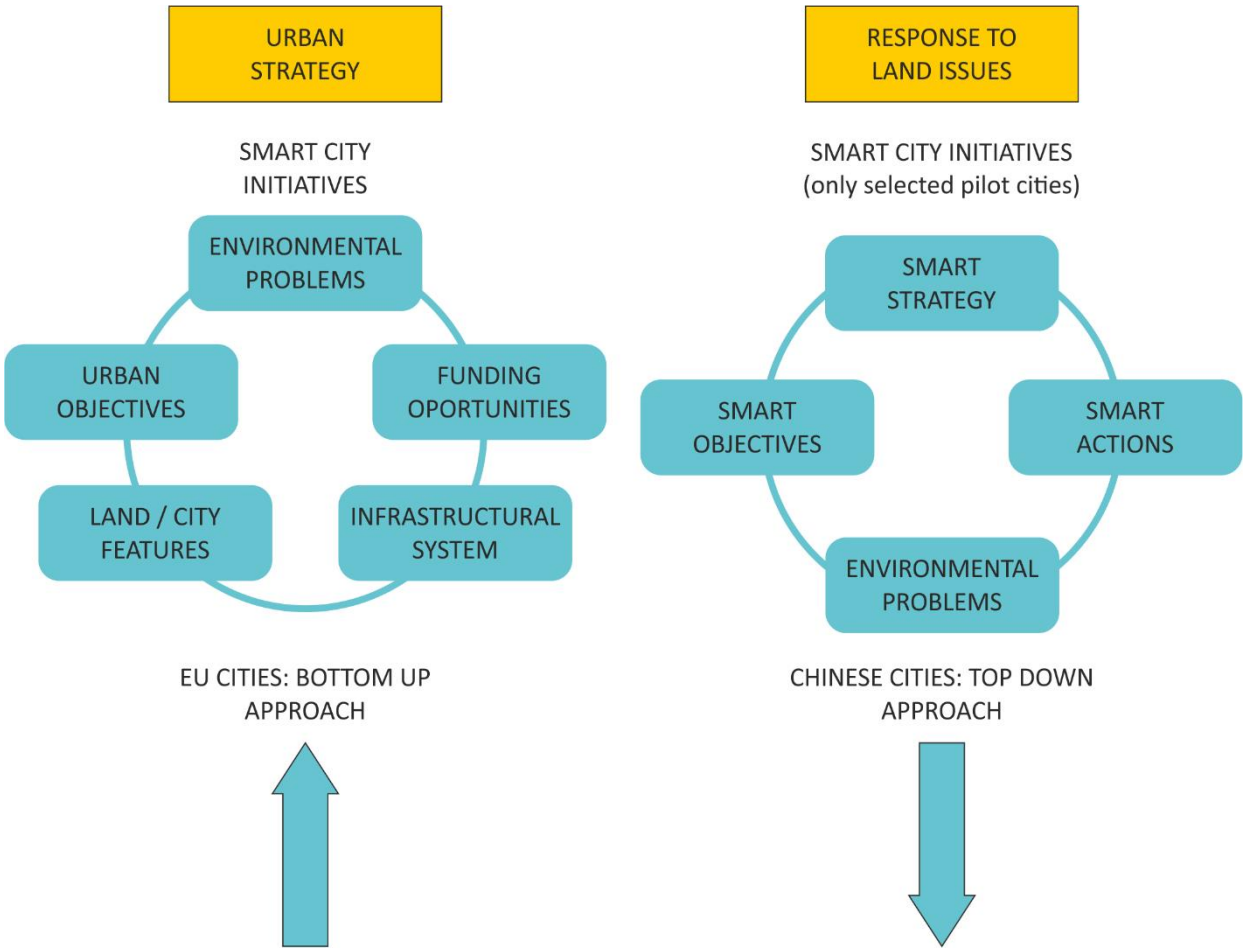

Figure 8. Comparing Different SC Visions: Bottom-Up (EU cities) and Top-Down (Chinese cities) Approach.
Source: (Sanseverino et al., 2018).

At the same time, the issues related to developing the city/municipality and its inhabitants are optional, i.e. the local government administration may, but is not obliged to, carry out consultations with the citizens on the issues concerning the quality of life in the city or solutions influencing it.

The authors prefer the bottom-up approach. However, it should be considered whether, with such large areas of ignorance (*Fig. 6 and Fig. 7*), an optimal bottom-up design of a Smart City or a Smart Sustainable City is possible. What model should be used to optimize such design and management? It is required to return to the initial assumption adopted in this article. Knowledge is the key to success in this area, as well as its dissemination and assimilation. In fact, it is the basis for creating competencies that can be used in the bottom-up approach to designing and planning the development and effective management of a Smart City. Under an ideal model, the whole knowledge accumulated and created at universities, technical

universities and research institutes should be evenly disseminated and distributed through educational institutions, universities and lifelong learning institutions *(Fig. 9).* A well-educated society can implement the participatory management model of a Smart City and a Smart Sustainable City. The educated society is also aware of its needs and rights, but at the same time understands the limitations of shrinking resources or environmental degradation, and can, therefore, participate in management in a more responsible way. After all, the very process of involving the local community in management processes is one of the important aspects of creating a Smart Sustainable City. In fact, knowledge resources reach only a part of society, namely the intellectual elite *(Fig. 10).* Their percentage is much higher in developed countries compared to those which are still at the stage of development. However, even in developed countries, with a high level of scholarisation, the idea of lifelong learning is still not very common, thus making the area of ignorance unlikely to shrink. Of course, it is not possible that all accumulated and created knowledge is absorbed by the general public. This is rather about ensuring that, through systematic and constant knowledge expansion, society is able to support management processes in a professional manner, while creating a better world for itself and others.

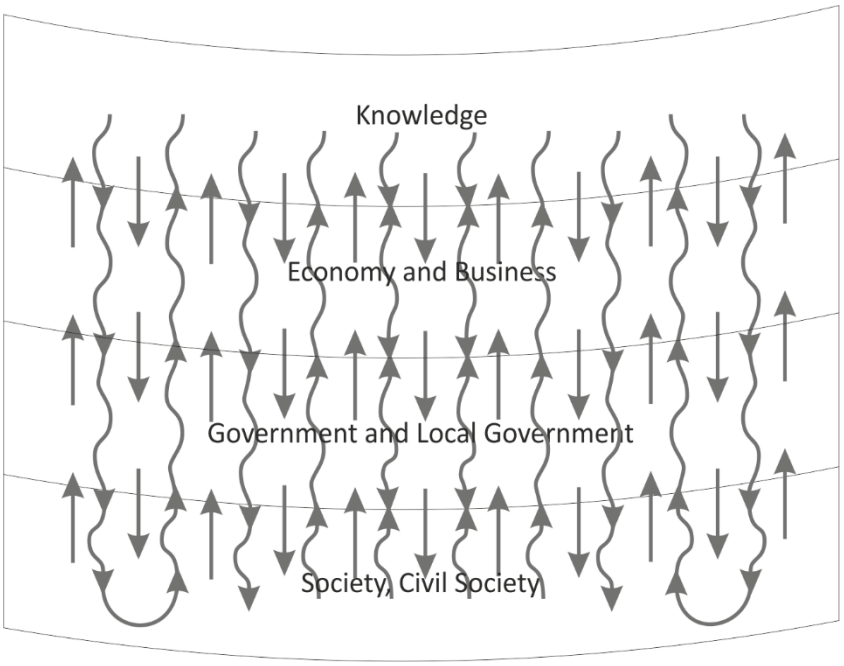

Figure 9. The Model of Knowledge Dissemination and Distribution for the Needs of the Participatory SSC Management Model
Source: the authors' own elaboration.

The idea of lifelong learning is particularly important for computerization and digitization, which are inseparable from implementing Smart City and Smart Sustainable City solutions and their operation.

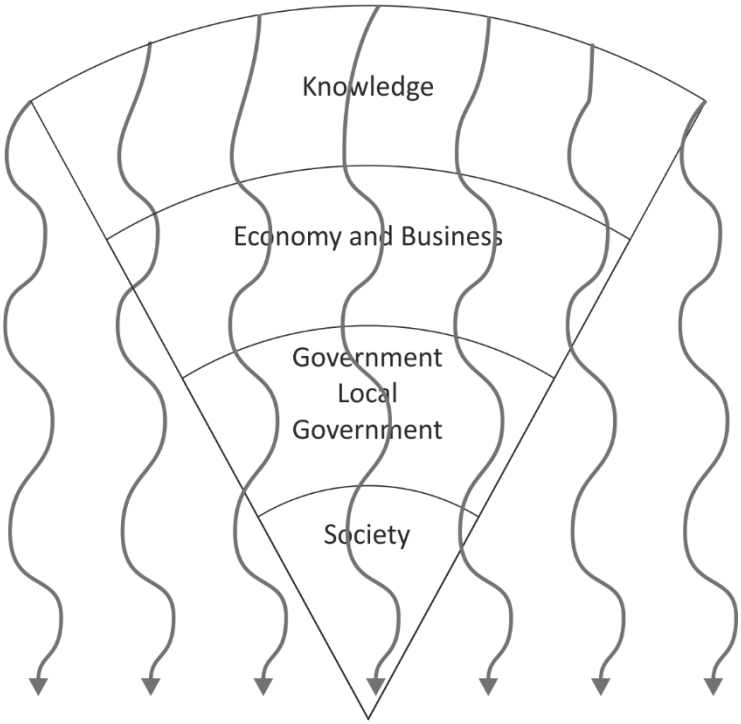

Figure 10. The Model of Knowledge Dissemination and Distribution Top-Down and Wastage of Knowledge
Source: the authors' own elaboration.

As it has been emphasized several times, civic participation in management must be based on a solid factual preparation, as well as on the knowledge that one possesses, which is the basis for shaping appropriate competencies as follows: digital, cognitive decisional, analytical, entrepreneurial and ethical. These are competences of the modern society, sometimes called society 4.0, which has been formed on the basis of the information and knowledge society. Proper education, including knowledge dissemination and distribution, can minimize potential negative manifestations of social development in the era of the fourth industrial revolution such as the social polarisation associated with the division into the IT/ICT industry creators and users. It will dominate all the sectors of economy, individual and social life, as well as the social exclusion of those who are neither creators nor users due to technological illiteracy. However, paradoxically, this group of technological illiterates will be less threatened with infantilization than users who, as a result of the thoughtless use of the products and services of Industry 4.0 and IT/ICT and AI technologies, may lose their ability to think independently, capacity for reflective approach to reality and their natural creativity. Intellectual laziness which will characterize users may lead to biological and psychological changes and regression of human nature, as well as distinctive features of the human species, such as consciousness, free will, morality, creativity, abstract and symbolic thinking, ability to cooperate and, consequently, the dependence of natural intelligence on artificial one, which, combined with intellectual laziness, can lead to learned helplessness. Therefore, the key areas of education should not only counteract digital exclusion, but also prepare and continuously improve ethical, personal and

social competences, which prepare for participatory holistic co-management of Smart Sustainable Cities, based on generational and intergenerational responsibility (Kuzior, 2017).

5. Conclusions

Taking into account the above considerations, it should be accentuated once again that the basis for an optimal model of urban management and creation of a Smart City and a Smart Sustainable City is knowledge properly disseminated and distributed, as a condition for acquiring interdisciplinary competences. It should also be emphasized that cities develop for their inhabitants, without whom they are empty and die. Therefore, a holistic model of Smart City management should be adopted, aiming at shaping a Smart Sustainable City on their ground, i.e. such management solutions that do not exclude any group of stakeholders and any urban system or subsystem bearing in mind the environment and future generations. It should also be remembered that the dynamics of innovative technologies development is already so strong that the Smart City development issues should be also seen in the context of developing cognitive technologies and artificial intelligence (Kuzior et al., 2019a; 2019b; Kwilinski et al., 2019). Skilful use of the aforementioned technologies by the entities involved in management can bring positive results. However, it must be remembered that designing a Smart Sustainable City must not adopt pre-imposed solutions that may not be accepted by the urban community. These should rather be ideas jointly elaborated with various stakeholder groups and adapted to local development policies. Local administration and business should pay attention to the citizens' opinions and identify their needs, as well as jointly design solutions that will improve the quality of life in the city (bottom-up model) in order to ensure safety in various areas of urban community functioning, both individually and collectively, as shown in *Fig. 11.*

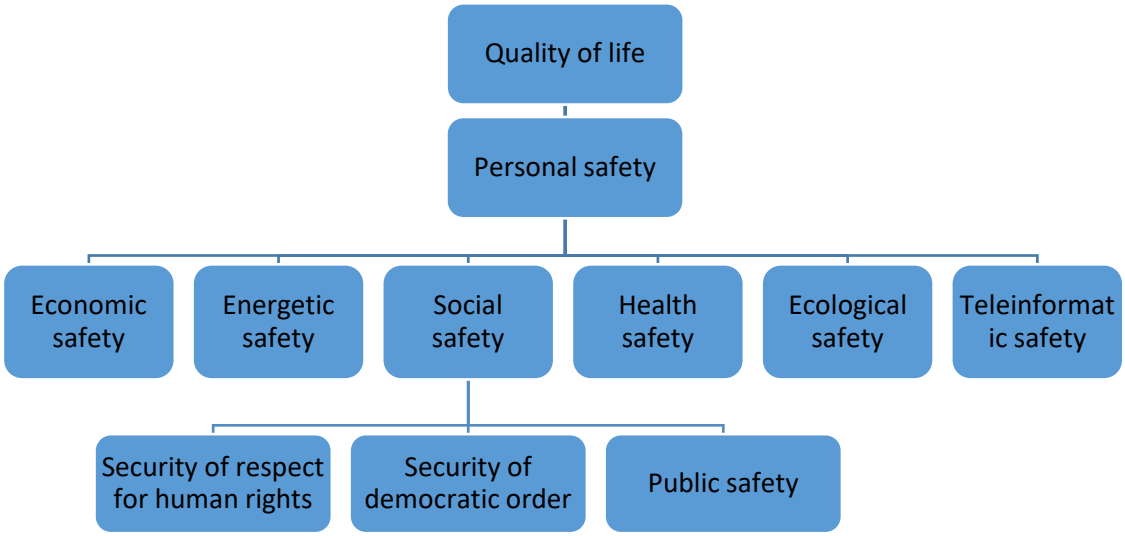

Figure 11. The Quality of Life Components in the SSC.
Source: (Kuzior, 2014).

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