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Perspective

Smart city as the supporting concept for the development of eco-city

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Abstract: This paper discusses the concept of creating a new reality using the approaches of smart cities to develop eco-cities, in which the necessary balance between nature and progress can be maintained. The authors propose that the concept of smart cities should be used as a tool for the creation of eco-cities, and argue that the positive synergies between the two will be strongest if the smart concept acts as a tool for the creation of eco. The core elements of a smart eco-city are identified as smart sustainable use of resources, a smart sustainable healthy community, and a smart sustainable economy. The results of the article were the foundation for the development concept for Vision Bratislava 2050—the vision and strategy for the development of the capital of the Slovak Republic. The authors also discuss the challenges of transforming cities into smart eco-formats, including the need for digital resilience in the face of potential cataclysms. They suggest that this is a promising area for further research into the concept of smart eco-cities.

Keywords: smart city; smart eco-city; urban transformation; sustainable development

1. Introduction

In the ages of Manufacturing X development, the Population fully plunged into the technological world stepping back from the natural. On the one hand, surely we, humanity, have gotten quick access to attributes of a comfortable life. Our "new normal reality" include being back in the public spaces, being back to places instead of territories, enjoying personal interactions, being less limited in our traveling, using the whole scale of public services, enjoying the advantages of a new reality, more homework and higher flexibility supported by ICT, better online services, new energy of public involvement, a forthcoming extension of our existential space and profiting from new dynamics of economic and societal transformation catalyzed by COVID19 pandemics (Dávid, 2024; Faludi, 2018; Pinto, 2008; Nelson, 2009; Simmel, 1903; Singh, 2019; Wirth, 1937; Zaman, 2024; Zijderveld, 2017).

The quality of life saw a significant improvement over the last century, primarily due to better access to services. However, rapid industrialization and growing urban populations have posed major challenges for administrators, architects, and urban planners (Eremia, 2017).

But on the other hand, we have come to live in conditions that are not intended for the human species and the other side of the coin has brought many new problems. This is the "new normal reality" we are confronted with too:

- production and consumption levels are overshooting our planet's bio-capacity by 50% per year, 284 m^2 of built-up area per inhabitant in OECD countries, almost 3 times the world average;

- 800 million people suffering from hunger, 663 million people lacking access to clean water;
- the accelerated divergence between advanced and developing economies;
- up to 16.6 million deaths associated with COVID-19 in 2020–2021 (WHO estimation);
- the hybrid war escalated by the aggression against Ukraine (migration, poverty, energy shortage, inflation, migration, security problems);
- multiple tensions resulting from different dynamics in urban social ecosystems.

The prospect of the negative effects of Industrialisation 4.0. will outweigh the benefits gained requiring specialists and scientists in the fields of territorial management, spatial planning, sustainable development, etc. to find compromises that will zharmonize natural space with technological progress to improve the quality of people's lives.

The year 2030 is fast approaching as a crucial deadline in the global effort towards sustainable development. Established in 2015, the UN Sustainable Development Goals (SDGs) serve as a roadmap for creating a better and more sustainable future. Similarly, the Nationally Determined Contributions (NDCs), which represent each country's commitment to reducing national emissions and adapting to climate change impacts, are also aligned with this date. Despite some progress, with only 2000 days remaining until the deadline, there is a growing global consensus that we have not done nearly enough to achieve these targets. (Arcadis Sustainable Cities Index, 2024).

Therefore, a gap arises—how to combine the technological (SMART) and natural (ECO) worlds in a single system while preserving the advantages of each as much as possible.

Eco-cities worldwide are increasingly adopting and utilizing the advancements of smart cities, particularly in advanced ICT and big data technologies, to monitor, assess, and enhance their sustainability performance, focusing especially on environmental and economic aspects (Bibri, 2021).

The authors believe that positive synergies will be strongest if the SMART concept acts as a tool for the creation of ECO.

Therefore, based on this statement, the authors of the article propose to consider the concept of creating a new reality using SMART cities approaches to develop ECO cities in which the necessary balance between Nature and Progress will be maintained.

2. Materials and methods

2.1. Methodology and limitations

This study employs a comprehensive approach to analyze and synthesize existing literature on smart eco-city concepts and their integration, drawing from a range of scholarly sources, reports, and policy documents. The research methodology involves a systematic review and narrative synthesis of relevant literature, aiming to identify key themes, trends, and theoretical frameworks related to smart eco-cities.

The primary sources of data include academic databases such as Web of Science (WoS) and Scopus, where peer-reviewed articles, conference papers, and reviews on smart cities, eco-cities, and their intersections were systematically searched and

retrieved. The search terms used included variations of "smart city," "eco-city," "sustainable urban development," "smart technologies," and related concepts. The inclusion criteria focused on articles published in the last decade (2010–2020) to capture contemporary perspectives and advancements in the field.

The retrieved literature was analyzed using thematic analysis and narrative synthesis methods. Thematic analysis involved coding and categorizing the literature based on recurring themes and concepts related to smart eco-cities, such as technological innovations, environmental sustainability, community engagement, and governance structures. Narrative synthesis was employed to systematically review and integrate findings across different studies, identifying patterns, contradictions, and gaps in the literature.

While comprehensive, the study acknowledges several limitations. Firstly, the reliance on academic databases like WoS and Scopus may exclude relevant literature not indexed in these platforms. Secondly, the search terms used may influence the scope of the retrieved articles, potentially overlooking studies using different terminologies. Finally, the qualitative nature of thematic and narrative synthesis methods may introduce subjectivity in data interpretation despite efforts to maintain rigor through inter-coder reliability checks and triangulation of findings. By employing these methodologies, this study aims to contribute a synthesized understanding of smart eco-city concepts, highlighting opportunities and challenges in their integration for sustainable urban development.

2.2. Previous research materials

World Cities Report 2022 by UN-Habitat offers insights into the future of cities, addressing trends, challenges, and opportunities for sustainable urban development, including lessons from the COVID-19 pandemic. In this report it was defined that climate change and environmental concerns are increasingly impacting urban areas, necessitating urgent adaptation and a transition to net zero greenhouse gas emissions. Current policies often lack ambition, relying on underdeveloped technologies and neglecting local governance. Urban inequalities are exacerbated by climate impacts and biodiversity loss, making it crucial to align social and environmental justice with policies like the SDGs. The post-pandemic period presented a brief opportunity for sustainability transitions, but rising emissions have hindered progress. A just transition must consider the informal sector's role, integrating their needs with technological advancements. Policymakers should support urban areas through coordinated, multi-level governance and nature-based, inclusive solutions. Involving diverse voices in planning reduces uncertainties and avoids technocratic limitations. International partnerships and social movements are key to fostering innovation and resilience. Recognizing diverse knowledge, including indigenous insights, is essential for effective environmental decision-making, and empowering vulnerable groups as change agents (World Cities Report, 2022).

Cities in today's world are finding it hard to be livable, environmentally friendly, and economically strong all at the same time. Balancing the immediate needs of today without compromising the needs of tomorrow is what is required from cities today. An eco-city is a city that continuously aims to be environmentally efficient and

eliminate carbon waste; meanwhile reducing poverty, generating employment, and creating a sustainable place for its inhabitants. A sustainable city or eco-city creates a stable way of life for its citizens across four domains namely; ecology, economics, politics, and culture; the main pillars of sustainability (Smart Eco-City, 2017).

There are numerous eco-city models, primarily based on adhering to urban ecology principles or integrating sustainable city strategies with smart city solutions. (Bibri, 2021).

"Eco-cities" aim to eliminate the negative impacts of current urbanization, striving to be environmentally neutral or positive. Designers focus on four primary areas: energy, water, waste, and transport. According to the Clinton Climate Initiative and the US Green Building Council, which are jointly promoting "climate positive" cities, key requirements for an eco-city include a self-contained economy, 100 percent carbon-neutral energy production, an integrated transport system that encourages walking, cycling, and public transport over cars, a zero-waste management system, resource conservation maximizing water and energy efficiency, preserving open spaces, wildlife, and plant habitats, and using environmentally sound, preferably locally sourced building materials (Green Vision). Bibri and Krogstie (2020) noted the challenge of defining a clear, comprehensive vision of an eco-city. Their research identified various eco-city models that focus on planning and developing sustainable cities and communities based on two primary design principles and strategies: passive solar design and greening (Jabareen, 2006). While these models share some features, they often emphasize different aspects and meet different criteria, including holistic approaches, subsystem interconnections, adaptability, and ecological sustainability-focused planning and design procedures. Models emphasizing passive solar design include ecovillages, solar villages (Van der Ryn, 1991), Solar City (Joss, 2011), and cohousing (Roelofs, 1999). Models combining passive solar design and greening include Eco-City (Engwicht, 1992; Roseland, 1997), Ecological City (Ecological Cities Project), Environmental City, Green City, Sustainable City (Gibbs et al., 1998; Girardet, 1999; Nijkamp, 1994), Sustainable Neighborhood (Rudin and Nicholas, 1999), Sustainable Urban Living (Girardet, 1992), Living Machines (Todd and Nancy, 1994), and Garden City (Zhou and Williams, 2012). Other models based on green or smart technology solutions for environmental sustainability include SymbioCity (Ranhagen and Growth, 2021), Carbon Neutral City, Zero Energy City, Zero Carbon City, eco-Municipality, eco-Industrial Park, Low Carbon City (Ranhagen and Growth, 2021; Roelofs, 1999), Net Zero Carbon Community (McGregor et al., 2013), Eco2 City (Cowley, 2016; Suzuki et al., 2010;), Smart Eco-City (Späth, 2017), and Ubiquitous Eco-City (Yigitcanlar and Lee, 2013).

Eco-city and smart-city visions often face criticism for neglecting the social and political dimensions of real urban spaces (Cowley et al., 2020). Professor May Tan-Mullins highlighted that urbanization trends have shifted more populations from rural areas to cities, with an estimated 70% of the world's population expected to live in urban areas by 2050, underscoring the importance of researching smart eco-cities (Smart Eco-Cities).

Currently, there is no comprehensive category of smart sustainable city indicators in the literature. Studies by Bibri et al. (2020) and Chowhan et al. (2022) highlight the key strategies of the eco-city district model and how they complement each other in

achieving sustainability's tripartite value, showing how eco-city district models support environmental, economic, and social sustainability goals. However, while environmental goals are central to planning, economic and social goals often take a secondary role.

Whitehead (2011) critically examined neoliberal urban projects, exploring how these cities, through 'smart' restructuring, embrace a holistic sustainability vision. Pira (2021) discussed the origins of sustainable urbanism and emerging challenges to its legitimacy in the context of climate change. McLaren and Agyeman (2015) provided a comprehensive literature review on SIDs and data-driven smart eco-cities, offering new insights by combining narrative and best-evidence synthesis approaches. Peris-Ortiz (2016) identified common sustainability and smart city features to propose a unique combined category of smart sustainable city indicators, which can guide academics and policymakers in building smart sustainable communities.

Rodrigues and Franco in their research examined the role of creativity and smart technologies in developing sustainable urban environments. They defined that the relationship between eco-cities and sustainability remains a fertile area for research, aiming to transform sustainable cities into eco-cities rather than building new ones from scratch.

3. Results and discussion

3.1. Vision of smart eco-city concept

For the development of the concept of creating new smart eco-cities, it is necessary to understand the difference between the smart city concept and the eco-city concept.

In Innovation for Sustainable Development Reviews (Innovation for Sustainable Development Reviews), authors defined that smart city as a concept based on the use of different types of smart solutions—technology, social, institutional, environmental, and economic innovations including ICT to supply information that is used to manage assets and resources efficiently addressing all sectors and fields of urban life including the interchange between the city and its functional areas.

The smart city concept is presented in **Figure 1**.

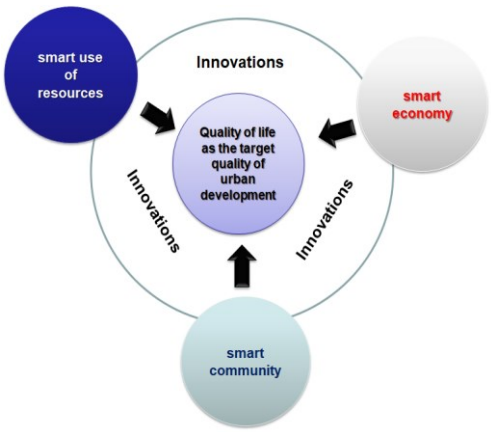

Figure 1. Concept of smart city.

On the other hand, ECO city is designed based on principles of harmonious living with the environment. Its primary objectives are to eliminate all carbon waste, generate energy solely from renewable sources, and integrate seamlessly with the natural surroundings. Additionally, it aims to support economic growth, reduce poverty, and enhance health through higher population densities and increased efficiency.

The concept appeared in 70th, California, advanced in the 1990 International Eco-City Conference, Berkeley, and conferences in Adelaide, Yoff, Curitiba, Shenzhen, Bangalore, and others.

The concept of eco-city is seen in **Figure 2**.

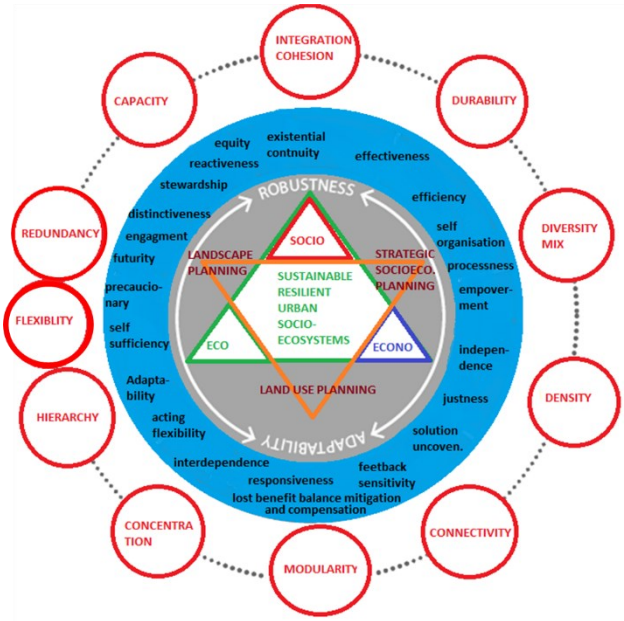

Figure 2. Concept of eco-city.

Urban systems are specific, highly open and complex social-biophysical entities whose development is influenced by numerous unpredictable internal and external factors, as well as decisions made by multiple actors, leading to significant uncertainty in their development.

Therefore, based on the above model's authors propose the next principles of integration of smart and eco-city concepts in smart eco-city concept:

- quality of urban socio-ecosystems guarantying equal access to the quality of life of citizens, quality of natural ecosystems, quality of the economic environment, and satisfaction of the visitors as the main target function of development and development management;
- efficient and sustainable functioning, efficient use and capitalizing of all resources (natural (incl. ecosystem services), financial, human, and technological) as well as the potential for collaboration and work division between the city and its functional area;
- traditional service networking is more efficient in satisfying the citizens and entrepreneurs thanks to the broad use of INNOVATIONS (incl. ICT, nature-based solutions, ecosystem services);
- ability to react flexibly to current and future challenges and adapt to the needs resulting from other external and internal impulses like climate change,

development of the global economy and its volatility, forthcoming globalization and internationalization, and others;

- concept going beyond simple implementation of ICT and other advanced innovative technologies looking for synergies, integration, and harmony between nature, technology, and humans;
- more interactive, sensitive, reflective urban governance, safe public spaces, and satisfaction of the needs of all citizens, entrepreneurs, and other stakeholders across different age and social groups.

The model of integration of smart and eco-city concepts into the smart eco-city concept is shown in **Figure 3**.

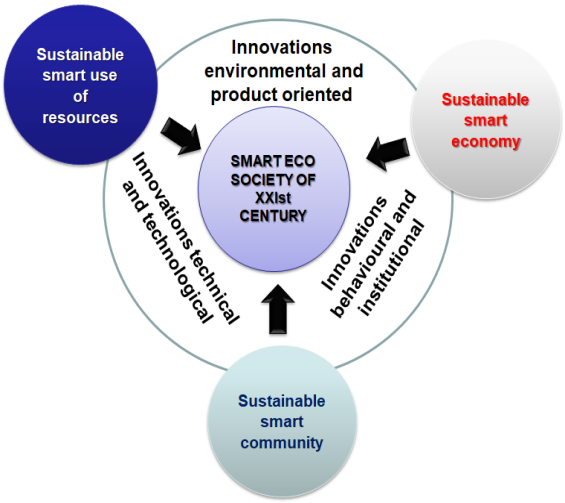

Figure 3. Concept of smart eco-city.

As presented in **Figure 3**, the core elements of a smart eco-city are smart sustainable use of resources, smart sustainable healthy community, and smart sustainable economy.

(1) The smart sustainable use of resources aligns with the vision of a smart eco-city as a system that ensures the efficient and sustainable utilization of natural, human, institutional, and financial resources, including information, data, know—how, advanced technologies, approaches, and processes.

(2) The smart sustainable healthy community consists of citizens, entrepreneurs, visitors, service users, and other stakeholders creating a smart social environment for their activities. This community operates under clearly defined, fair, inclusive, equal, transparent, open, multicultural, multiracial, and gender-balanced rules, sharing common values and goals to optimize their quality of life. This includes efficient and sustainable use of available resources, including high-tech technologies, for living, working, entrepreneurship, and other activities.

A smart sustainable economy is a system of transformative processes where resources are used to produce values/products (goods, knowledge, services, environmental quality) and improve the environment for these processes. This economy is dynamic, competitive, efficient, and sustainably leverages and develops regional and local territorial capital. It is knowledge-based, innovation and creativity-

oriented, excellence-driven, environmentally friendly, and generates high added value outputs.

Crucial for recognizing the importance of integration of the smart cities and eco-cities concepts is the understanding of the synergies between them. The smart city concept, focusing on the efficient use of different kinds of technology, social, environmental, and other innovations in urban life and development predominantly deals with these innovations as new approaches, tools, and instruments addressing the process of urban transformation and services framing new quality of city satisfying better the needs of its citizens, visitors and other users. The concept of eco-city outlining exactly this required new quality, it means defining the target quality and framework precondition for sustainable efficient implementation of innovations. The concept of a smart city can be integrated with other concepts than eco-city defining different target qualities in urban development. But the synergy of these two concepts is crucial for a clear orientation of urban transformation addressing current challenges and problems by proper solutions reflecting achievements of the 21st century and at the same time avoiding negative synergies or contraindicative use innovations in the context of environmental, and social and economic sustainability. Clear targeting of the choice and use of innovations offered by the smart city concept towards balance between all dimensions of sustainability as defined by the eco-city concept can avoid e.g. growth of vulnerability of cities due to growing dependency on new technologies sensitive to blackouts in energy supply systems, social exclusion caused by lower affordability of services for different social groups or by their specific ability barriers in approaching new technologies, implementation of high energy consuming technologies instead of nature close solutions and others we experienced recently in our cities and households.

3.2. Smart eco-city urban transformation

The urban transformation from smart-to-smart eco-city demands changes in different key urban life factors:

3.2.1. New urbanity

The urban population accelerated during the last two centuries as the cities represent attractive places for life, work, business, and tourism. The way and symptoms of this growth are changing with the shift of driving forces of urbanization. The development of industry, as the driving force of urbanization in the 20th century benefiting from a concentration of human resources, proximity to raw material resources, various infrastructure connection points, and horizontal cooperation ties in production processes is going to be replaced by new attractors of economic development in a post-industrial knowledge-based society. Recent overall societal transition with its complexity and deepness determines a new view of cities as attractive localities for economic activities and dwelling. Urbanity is a specific essential quality of urban being linked to a specific quality of life, the quality of the cities differentiating them from rural environment and core of their attractiveness, as a product of interactions in urban society, spaces, volumes, functions are framing the development of urban communities and urban economy and in the same time is a product of their development processes. In this context, urbanity as the core quality

and object of urban competitiveness is more and more defined by new attractors creating new post-modern urbanity radiating across the border of the cities into the broader urban functional areas. We can speak about changing the contents of urbanity or about new urbanity.

The shift to new urbanity is framed by 4 main shifts as follows:

- The shift from urbanity based on the freedom of citizens and other users of an urban environment to choose from a variety of resources (services, working places, activities, infrastructural systems) based on the density of resources available in the cities to the urbanity based on the freedom to join and to share resources based on the density of networks and interhuman interactions. This dimension of new urbanity has been crucial for the reurbanisation processes at the end of the 20th century.
- The change of urbanity as an attractor is based on proximity to a variety of resources the proximity to knowledge and the impulses for creativity based on a variety of interactions in urban spaces.
- The importance of the number of interactions given by the concentration of activities and peoples in the urban environment is in new urbanity replaced by potential synergies as the results of the interactions not distinguishing between productive and non-productive activities. The higher effectiveness and efficiency of human activities in urban areas are given by the synergies between social, behavioral, economic, technical and technological, and environmental innovations.
- The typical linkage of urbanity to the physical and functional urban environment is lowered by the extension of urbanity into the virtual space using information and communication technologies, hand by hand with the development of new spatiotemporal functional structures allowing new kinds of polyfunctionality and more efficient use of urban spaces, buildings, and infrastructural elements. This shift has implications for the development of a new quality of urban population too.

3.2.2. New quality of the urban population

The urban population used to be defined based on the citizenship of the people in the municipalities with the official status of cities. The validity of this definition is questionable not only due to the different preconditions for the institutionalization of them as official cities. As the core quality of the urban environment is urbanity linked to the specific quality of urban life, the urban population needs to be characterized as the population with the urban way of life.

The affordability of this quality beyond the administrative borders of institutionalized cities expanding into the urban functional areas and virtual space accessible from different places, together with the growing mobility of the population and shrinkage of physical distances due to infrastructural development brings this specific way of life to the more and more peoples living outside of official cities.

A big part of the population, officially dwelling in the villages, takes an active part in urban life, co-creating and profiting from the new affordability of urbanity. They commute to the cities for work, education, and leisure time activities, and they enjoy the offer of urban services being physically or virtually present in urban spaces.

An important aspect of urbanity is the offer of physical frameworks for peoples` existential continuity in space and time, and the identification and positioning of individuals and communities. The growing expansion of peoples' existential space changes the preconditions for their identification in space and time, shifting the scale of "belonging" from local to micro-regional to regional and macroregional in which the reference to the urban physical environment semiotics used to be dominant.

The European rural environment became, in the context of the transformation of its economic base, improvement of accessibility of public services and physical structures of rural settlements, full-fledged complementary quality to the cities, in which the preconditions for a specific way of life should be developed, different from that in the cities. The further development of this specific quality, offering an alternative, not lower but a different quality of life (perhaps much closer to nature and more resilient) can enrich both the urban as well as rural populations.

3.2.3. New fuzzification and virtualization

Urban spaces have traditionally been understood as fixed, bounded entities, defined by clear boundaries and distinct territories. However, the concept of fuzzification challenges this traditional understanding by positing that urban spaces are increasingly becoming more fluid and indistinct.

Part of the population can be attributed only to the urban population, and part only to the rural population (completely true or completely false values on the figure). However, some part of the population is partially urban and rural at the same time. As a result, we can speak of the deterritorialization of urbanity that leads to the concept of switching from territories to places.

This process of fuzzification is driven by various factors, including technological advancements, globalization, and the blurring of traditional boundaries between different urban areas.

One of the key factors driving the fuzzification of urban spaces is the increasing integration of virtual space into the everyday functions of citizens. For example, the rise of the internet and digital technologies has enabled the proliferation of online marketplaces, which have transformed the way we shop and consume goods. Similarly, the widespread adoption of telecommuting and remote work has enabled people to perform many of their everyday functions from anywhere, blurring the traditional boundaries between work and home. Such processes as well can be represented by fuzzy logic, when the same workplaces are partially real and partially virtual at the same time. And people show a willingness to work from home (Barbour et al., 2021). In such conditions, we can speak about the dematerialization of urbanity and the extension of urban functions into virtual space.

The fuzzification of functional spaces has become an increasingly important topic in recent years due to the rapid development of technology and the corresponding changes in how we use and occupy physical space. With the proliferation of mobile devices and the increasing use of the internet for both work and leisure, functional spaces have become more overlapping, multifunctional, and spatially and temporally dynamic.

One of the primary ways in which technology has contributed to the fuzzification of functional spaces is through the increasing overlap and blurring of boundaries

between different types of space. For example, with the rise of telecommuting and remote work, the home has become a functional space for work as well as leisure, while public spaces such as coffee shops and coworking spaces have become places where people can work and socialize.

Another way in which technology has contributed to the fuzzification of functional spaces is through the increasing multifunctionality of spaces. With the rise of smart cities and the Internet of Things (IoT), physical spaces are being equipped with a wide range of sensors and other technologies that allow them to be used for multiple purposes. For example, a public park may have sensors that collect data on air quality and weather patterns, as well as WiFi hotspots and charging stations for mobile devices. This multi-functionality of space has the potential to transform the way we use and interact with physical space, making it more adaptable and responsive to our needs and preferences.

The concept of social fuzzification refers to how traditional social hierarchies and structures are becoming increasingly fluid and uncertain, resulting in a new stratification of society. This trend is driven by a variety of factors, including technological advances, economic globalization, and changing cultural and social norms.

One of the key ways in which social fuzzification manifests itself is through the blurring of boundaries between different social groups and the corresponding erosion of traditional social hierarchies. For example, advances in technology and communication have made it easier for people to connect with others who share their interests and values, regardless of their geographic location or social background. This has led to the emergence of new social networks and communities that transcend traditional boundaries and hierarchy, such as online communities and social media platforms.

At the same time, social fuzzification is also leading to a reconfiguration of the scales of belonging and identification. With the increasing mobility and interconnectedness of modern society, people are more likely to have multiple identities and allegiances that span local, regional, and national scales. For example, an individual may identify as a member of a local community, a regional culture, and a national nationality, all at the same time. This fluidity and flexibility in social identities can create new challenges for policymakers and communities as they strive to define and address the needs and interests of their constituents.

3.2.4. New synergies of innovation

If we consider the city as a real socio-ecosystem, then innovations will be a part of the core quality and source of dynamics of the urban environment. Synergia of innovation has to be directed to merge processes of urban metabolism, that used to analyze the flows of the materials and energy within cities, and urban development (incl. urbanization) which covers infrastructure for different institutions of an eco smart-city, like education, health, justice, solid waste, markets, street pavements, and cultural heritage protection.

On the one hand, urban metabolism will provide a framework to study and develop the interactions of natural and human innovations in eco smart-city. And on the other hand, urban development will deliver capacity-building measures. It is

especially necessary to pay attention to the research of innovation for digital resilience, rehabilitation, and reconstruction against natural disasters or conflicts that could touch smart eco-city. Another important thing is the search for innovation in ecological development, usage, and utilization of smart decisions. For the sustainable development of a smart eco-city The UNECE Innovation for Sustainable Development Review (I4SDR) offers a comprehensive understanding of national and regional innovation systems through a detailed assessment and recommendations for policy and structural reforms. These are grounded in international best practices and a thorough understanding of specific national and regional contexts.

3.2.5. New urban ecology

Cities comprise complex socio-ecosystems developing under the preconditions of high uncertainty influenced by external development framework dynamics as well as by multi-actor decision-making. Continuous innovations became core elements of urban dynamics in which urban functional and physical structures are constantly adapted to the developing needs of society and situations. This dynamic is crucial for the sustainability and resilience of cities depending on the ability to reflect the specifics of the nature-society system and to react properly to internal social dynamics and dynamics of the external environment including global climate change. To safeguard sustainable development and resilience of the cities representing the highest density of interaction in this system the interactions and synergy effects between different kinds of innovations (e.g., ecological, technical, social, behavioral, institutional) creating the content of urban transformation are needed. Deep knowledge of complex development and functional processes in urban socio-ecosystems is in this context crucial. New urban ecology is required to focus on new challenges linked no more predominantly with the protection of urban ecosystems, on adapting and harmonizing man-made environment with nature, not only on "greening" the cities or possibilities to safeguard sustainability by eco-innovations. New urban ecology has to develop and provide a conceptual framework for sustainable, efficient use of local urban territorial capital including urban ecosystems in a new innovation-based urban economy capitalizing the provision of urban ecosystem services and using the synergies between nature-based solutions and new smart technologies.

3.2.6. New urban economy

The new urban economy must be founded on quadruple-helix collaboration (QHC), involving research and development among four key societal sectors: industry, government, research institutes, and the public (quadruple-helix collaborations in Practice Stakeholder Interaction, Responsibility, and Governance). QHCs are expected to enhance problem-solving capacity for smart and eco-city initiatives by providing greater synergy. Individual organizations alone cannot address these complex issues; systematic change through these quadruple collaborations is necessary. By combining expertise and value-driven behavior from all four sectors, QHCs are anticipated to succeed where individual efforts may fail, fostering a more responsible innovation environment for urban transformation. These collaborations are likely to promote responsible integration of values and risk mitigation, crucial for developing eco-smart cities. Quadruple-helix collaboration will provide a systematic approach to efficiently use urban resources of smart eco-city. The best approach for it

is a circular economy that will improve resources of smart city efficiency and reduce environmental impact on natural capital by designing products in a more recyclable way, adopting efficient technology, and turning waste into a resource. Carbon-neutral economy capitalizing local/regional territorial capital incl. ecosystem services sustainably. To realize the circular economy QHC must adapt systemic approaches to address the remaining challenges to resource efficiency guided by the European Union-developed model (GGKP, n.d.).

Besides circular, it is necessary to have an innovation-based economy and digital economy that will capitalize a synergy between "smart" and "eco" parts of different kinds of smart eco-city innovations (social, technological, environmental, etc.) in a creative environment. The economy of innovation is established by encouraging entrepreneurship via expanding credit for startups.

Governments of smart eco-cities must innovate, collaborate, and develop new methods for service delivery, transparency, and participation. This involves making more data available online and using data analytical tools, social media, mobile technology, and search results to enhance decision-making. They should also strengthen infrastructure by investing in broadband, data centers, and mobile cell towers, as well as improving access to spectrum for wireless applications in smart eco-cities. (Governance studies at Brookline).

Another important component of a new urban economy is the health and care economy that covers an inclusive, socially-oriented economy with active aging capitalizing specific human capital of the city.

Health and the economy are closely interconnected, and evidence suggests that investing in health and healthcare systems contributes positively to achieving economic goals, even when the connection is not immediately apparent or obvious. Providing a resilient economy is an important element of the security of smart eco-cities in a local or regional economy because it covers the ability to anticipate risk, evaluate how that risk can impact key economic assets, and build a responsive capacity. A resilient economy is persistent-robust, adaptable-flexible, transformable-innovation-oriented.

3.2.7. New urban society

The development of a new urban society is closely linked to the new understanding of the urban population and the new quality of post-modern urbanity. Recent development catalyzed by the COVID-19 pandemic, the war in Ukraine, and the energy crisis show clear directions toward urban society consisting of the networks of smart resilient communities. Such communities can frame the required high quality of life of each specific community member sustainably following the shift from the functionalist model of the 20th century to the post-modern model of living environment (physical and social) in which inclusiveness and responsibility are crucial qualities.

The required flexibility in reaction to external shocks, the efficiency of place-based and evidence-based strategies for problem-solving and facing current and future challenges such as climate change, large-scale migration, and others can be achieved only by the development of self-learning and self-organizing capacities of the communities, their internal and external cooperation based on networks capitalizing

the diversity and complementarity of their territorial (human, natural, technological, financial, institutional) capital.

Expanding on digital resilience in the face of potential cataclysms is intriguing and relevant. Enhancing digital resilience in smart eco-cities is crucial for ensuring they can withstand and recover from various disruptions, such as cyberattacks, natural disasters, or other crises. Cities like Kyoto and Yokohama have implemented advanced technologies to enhance their disaster resilience and urban management. Kyoto uses next-generation digital signage, environmental sensors, and smart lights to collect and analyze data on human activity and environmental conditions, which helps improve urban management and disaster response. Yokohama powers its emergency information systems with renewable energy, ensuring energy availability during disasters. To further enhance digital resilience, cities can adopt a comprehensive cyber resilience framework, utilize big data analytics for informed decision-making, engage citizens in resilience planning, invest in smart infrastructure, and implement automation tools. Regular cybersecurity audits, robust disaster recovery plans, collaborative networks, and adaptive policies are also essential strategies. These measures ensure cities can maintain essential services, mitigate risks, and foster a culture of preparedness and resilience (Birbi, 2021; Nicholas, 2018; Kamtam, 2022; Remes, 2019; Samarakkody, 2023).

New urban society can be sustainable only by functioning based on principles of cooperation, tolerance, safety, security, and justness based on shared values, being governed by a polycentric multilevel governance system. The development of such a system means sharing responsibilities based on competencies to solve the problem or to face challenges in the most effective and efficient ways going even beyond the traditional territorial government structures fully in harmony with the concept of deterritorialization as explained by Faludi.

3.3. Practical implementation of smart eco-city concept

The above-described concept of Smart Eco-city became the core concept for the Vision Bratislava 2050—the vision and strategy for the development of the capital of the Slovak Republic (Finka, 2021), building up on Smart Twin City Bratislava concept elaborated by SPECTRA Centre of Excellence of the EU at Slovak university in Bratislava based on the collaboration of the key stakeholders in the city development—governance structures, R&D institutions, interest groupings, end-users, entrepreneurs, citizens in 2017. This vision and strategy emphasize that achieving smart and sustainable development relies on fostering horizontal and vertical connections and collaborative opportunities within the Central European metropolitan region, particularly between twin cities Vienna and Bratislava. Bratislava aims to position itself effectively within this shared economic and social innovative environment in Europe. The city aspires to harness its potential to become a leading metropolis in Europe and an integral part of the Central European Metropolitan Region. This includes cultivating a productive, knowledge-based economy, promoting a sustainable environment, and fostering a community capable of attracting and supporting the creative class, knowledge-based industries, research, and high-value enterprises. The goal is to encourage sustainable innovation while leveraging its

territorial assets effectively. From the point of view of methodology, the development of Vision Bratislava 2050 was divided into four phases:

- Active expertise and communication of the expert team and definition of the core concept for the Vison in collaboration with the city administration.
- Professional and broader public discussion on the needs, target qualities, problems and responses, potentials, limits, responsibilities, and cooperation potentials.
- Formulation of the vision a strategy, its presentation, and reflection on the feedback.
- Proposal of a roadmap for implementation of the strategy.

The interactive work on the strategy, including the exchange among different stakeholders and critical review of domestic and foreign experts, resulted in the formulation of policy principles, policy options, policy goals, and needed innovations/changes for each of the above-explained dimensions of smart eco-city in 3 main domains follows:

The smart use of resources is aligned with the SMART TWIN City vision, the approach emphasizes the efficient, sustainable utilization of natural, human, institutional, and financial resources, integrating available information, knowledge, advanced technologies, methods, and procedures. Key resource areas targeted for smart management include energy, land/soil, information, knowledge, data, building infrastructure, human and social capital, natural resources, spatial planning, materials, and institutional and financial investments. The primary innovations and advancements aimed at smart resource management include:

a) Technical, Technological
   - An integrated system of data collation, management, and accessibility
   - Smart transport system
   - Smart infrastructure using efficiently local and regional resources, oriented on the use of renewable resources
   - Smart services for citizens and entrepreneurs supporting their creativity, the high added value of their products, and the use of local territorial capital
   - Smart culture infrastructure (make use of local cultural resources)
   - Urban heat island mitigation strategy

b) Behavioural
   - New collaboration culture in Bratislava and thrust among stakeholders
   - The new institutional culture of the magistrate incl. the way of communication with the citizens and other stakeholders
   - A new approach towards waste as a valuable source of resources

c) Institutional
   - New institutionalized collaboration networks in the city and the metropolitan region Vienna-Bratislava
   - New integrative planning documents for city development integrating sectoral policies of the city based on a new philosophy of smart development of the city

d) Product-oriented
   - Bratislava as a smart product for tourism capitalising on local and regional territorial capital

- Bratislava as a smart environment for businesses capitalising on local and regional territorial capital
- Bratislava as a smart environment for living capitalising on local and regional territorial capital
- New ecosystem services provided by developed high-value urban ecosystems
- A new brand of SMART TWIN City Bratislava

The smart economy quality is interpreted broadly within the SMART TWIN City vision, the concept reflects a system of transformative processes where available resources are utilized to create value through goods, knowledge, services, and environmental quality. The SMART economy is characterized as dynamic, competitive, efficient, and sustainable, leveraging regional and local territorial capital. It is knowledge-based, fostering innovation and creativity, promoting excellence, and prioritizing environmental sustainability while generating high-value outputs. Key focus areas in the SMART economy include fostering a creative and innovative environment, supporting the science square comprising spinoffs, start-ups, and scaleups, valuing ecosystem services derived from natural capital, promoting the creative and cultural economy, advancing the circular economy, enhancing smart tourism, supporting shared economy initiatives, and promoting social economy enterprises. The primary innovations and improvements needed in the SMART economy include:

a) Technical, Technological
   - Smart business public infrastructure/technical and social infrastructure supporting business activities in the city

b) Behavioural
   - Joint development of the main economic policies, strategies, measures, and decisions

c) Institutional
   - The economic policy of the city stimulates innovations in business, culture and
   - A cluster of city smart creative economy
   - Cooperative institutional structures

d) Product-oriented
   - New innovation-based products in the economy worldwide competitive capitalizing local and regional territorial capital (natural, human, institutional, financial.)

The smart community quality within the SMART TWIN City vision, is understood as fostering a vibrant community where citizens, entrepreneurs, visitors, service users, and other stakeholders engage in a smart social environment. This environment promotes activities such as communication, competition, and collaboration based on clearly defined rules that are fair, inclusive, equal, transparent, open, multicultural, multiracial, and gender-balanced. The shared values aim to optimize their quality of life, encompassing living, working, entrepreneurship, and other activities. This is achieved efficiently and sustainably, leveraging available resources including high-tech technologies. Key areas of focus within the smart community include governance, participation, cooperation, security, education and

self-learning, mobility, and healthcare. The primary innovations and improvements required for the smart community include:

a) Technical, Technological
   - Technology platform for social participation of citizens and other stakeholders

b) Behavioural
   - Change the approach of city governance bodies to public participation towards transparency and efficient use of knowledge and skills of the citizens and other stakeholders in the city.
   - Change the behavior regarding the modal split of individual transport activities.

c) Institutional
   - The institutional platform for joint governance structure to connect the Twins, to solve jointly the questions of their development in a short and fast way through transparent processes

d) Product-oriented
   - New quality of smart self-learning fuzzy community

Development of the Vision Bratislava 2050, as well as its implementation, needs the involvement of all relevant stakeholders with their strategies, interests, and capacities, but the main precondition is the change of political thinking going behind election periods and short-term effects addressing potential electorate. The city administration needs to go behind the limits of everyday management of urban life just to reflect the most pressing problems and challenges. The main issue is the development, institutionalization, and functioning of proper communication and collaboration structures as it represents an integrative strategy across sectorial policies and hierarchical levels of governance structures related to the city starting with the city district level, via city as a whole up to regional level, with special attention to the urban-peri-urban interlinks. Flexibility and openness are the main attributes of each smart ecocity development strategy. Reflection of the dynamically developing needs, frameworks, and preconditions in the form of proper adaptation changes reflecting the multi stakeholders' interest is a natural part of Vision Bratislava 2050 as an open professional document supporting place-based and evidence-based decision-making in Bratislava.

4. Discussion

The results of this study indicate significant advancements in the integration of smart and eco-city concepts, providing valuable insights into sustainable urban development. By examining the Vision Bratislava 2050 strategy, the findings underscore the importance of a multifaceted approach that incorporates technological, behavioral, and institutional innovations to achieve a truly sustainable urban environment.

The primary findings from the Vision Bratislava 2050 project demonstrate that successful smart eco-city development hinges on the effective use of resources, innovative governance structures, and community engagement. The study highlights the necessity for integrated data management systems, smart transportation, and

infrastructure solutions that prioritize local and renewable resources. These elements are crucial for reducing the environmental impact of urban areas while enhancing their livability and economic potential.

Moreover, the research emphasizes the need for a cultural shift in collaboration and communication among stakeholders. The development of new institutional cultures and collaboration networks is essential for fostering trust and cooperation, which are vital for the implementation of sustainable urban practices. This aligns with the broader context of smart city development, which requires a holistic and inclusive approach to address the diverse needs and challenges of urban populations.

The findings from this study suggest several directions for future research. One critical area is the further exploration of the relationship between smart city technologies and social sustainability. While technological advancements are well-documented, their impact on social equity and community well-being requires a more comprehensive investigation. Future research could focus on developing metrics and indicators that better capture the social dimensions of smart eco-cities.

The integration of the two concepts—smart and eco-city itself needs to be further conceptually elaborated. The research focusing on synergies between technology innovations and environmental, social, and economic innovations, including the alternative use of other than technology innovations in response to current challenges and demands without increasing the vulnerability of urban socio-ecosystems seems to be a priority. The gap in understanding all three dimensions of sustainability—social, environmental, and economic in assessing the technological innovations is still not properly closed, even not speaking only about newest technological achievements broadly used in smart cities like IoT (internet of things) and artificial intelligence.

Another promising avenue for research is the study of behavioral changes necessary for the adoption of smart eco-city practices. Understanding the motivations and barriers faced by individuals and organizations in transitioning to more sustainable behaviors can inform the design of policies and initiatives that effectively promote these changes.

The implications of this study extend beyond Bratislava, offering a model that can be adapted to other urban contexts globally. The integrated approach to smart eco-city development, combining technological innovation with community engagement and institutional reform, provides a comprehensive framework for other cities aiming to achieve sustainability goals. In the broader context, this research contributes to the ongoing discourse on sustainable urban development, highlighting the importance of interdisciplinary approaches and the need for continuous innovation and adaptation. As cities worldwide grapple with the challenges of climate change, resource scarcity, and population growth, the lessons from Vision Bratislava 2050 offer valuable guidance for creating resilient and sustainable urban environments.

5. Conclusion

Recent societal trends highlight the increasing importance placed on concepts such as space and place, whether it pertains to cities, regions, or landscapes. Space, in general, is becoming a scarce resource, and determining its optimal use is not immediately evident. Finding the best approaches necessitates a creative and

collaborative effort. Spatial planning, which directs the future development of a territory, should be viewed as a dynamic process of decision-making and communication influenced by factors such as community, society, and the unique identity of a place.

In the article, the authors consider the concept of a smart eco-city, which includes the smart sustainable use of resources, smart sustainable healthy community, and smart sustainable economy. The developed concept of a smart eco-city was the core concept for Vision Bratislava 2050—the vision and strategy for the development of the capital of the Slovak Republic.

When transforming cities into smart eco-formats, the challenges of digital resilience must be taken into account. As Ukraine's experience during Russia's military aggression against it has shown, dependence on energy infrastructure makes cities and their residents incredibly vulnerable. After all, in devastating cataclysms, whether war or natural disaster, millions of people are left without the necessary conditions for life. For smart eco-cities, where such dependency is catastrophic, digital resilience is the most pressing issue and requires finding the best solutions for sustainability professionals. This is a promising area for further research into creating the concept of smart eco-cities.

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