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Smart City Resilience

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Due to the significant increase in the human population and its urbanisation, large urban agglomerations are increasingly coming under considerable pressure. In order to optimize this urbanization, most urban agglomerations are starting to use the Smart City concept. This concept is based on the integration of smart digital technologies into various aspects of cities and regions to improve the quality of life of citizens and reduce energy consumption. These aspects mainly concern energy, transport, communications and waste management. However, the functioning of the entire Smart City concept depends on the basic services of selected technical infrastructure, especially energy and ICT. As a result of the possible impact of various security threats that may result in incidents on the infrastructure in question, disruption of basic services can be expected, thus affecting the functionality of the entire Smart City concept. Based on these facts, it is essential that these infrastructure elements achieve the required level of resilience to withstand the occurrence of various incidents. For this reason, the paper presents two potential approaches to determine the factors that define Smart City resilience.

1. Introduction

As the 21st century dawns, there is an increasing emphasis on transforming what might be termed traditional towns that reflect the historical and cultural roots of their communities (Adelphi et al., 2020). In the context of increasing pressure caused by growing urbanisation and the dependence of the human population on modern technologies, these cities are forced to adopt the Smart City concept (Yin et al., 2015). This concept consists of integrating modern technologies such as sensors or the Internet of Things into urban systems to optimise the management of transport, energy, security and other key areas (Alahi, 2023; Gracias, et al., 2023; Lacson et al., 2023). Smart cities are defined as cities that use these technologies to improve efficiency, sustainability and quality of life for their residents.

One of the basic prerequisites for the functionality of the Smart City concept is a high level of resilience of its individual components, but also of the infrastructure on which the concept is based. However, assessing this level of resilience is currently very difficult as there are currently no explicitly defined methods for this purpose. A possible solution is to assess resilience through indicators related to different aspects of the Smart City (Sharifi and Khavarian-Garmsir, 2023). Another suitable approach is to assess resilience through factors related to critical entities. Critical entities are the owners or operators of infrastructure providing essential services, i.e. "*means a service which is crucial for the maintenance of vital societal functions, economic activities, public health and safety, or the environment"* (Directive 2557,2022). Critical entities can therefore be seen as owners or operators of the infrastructure necessary for building a Smart City, i.e. ICT and energy (Ma, 2021; Bifulco et al., 2016).

Based on these facts, i.e. the potential impact on the Smart City concept through disruption of essential services, it is essential that steps are taken to protect these entities and their infrastructure. In this regard, it is proposed to adopt the concept of resilience, which can be based either on the application of indicators characterizing the resilience of the Smart City or on the application of factors determining the resilience of critical entities. Based on this, the paper presents two possible approaches to define Smart City resilience factors.

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2. Perceptions of resilience in the context of the Smart City

The term resilience comes from the Latin word *resilio*, or to rebound. This term was first associated with the issue of ecological systems (Holling, 1973) and subsequently with other scientific fields. In the context of physics, this term has been used to describe the ability of materials to absorb energy and then return to their original state (Gordon, 1991). In relation to other scientific disciplines, the term has also developed in the field of safety engineering (Thoma, 2016). However, due to its considerable use across different disciplines, there is still no single, unified definition of resilience. The possible definitions related to urban resilience are therefore presented in Table 1.

Table 1: Definition of Smart City resilience

Definition	Publication
„Urban resilience is the ability of a city to recover from destruction."	Urban resilience and the recovery of New Orleans (Campanella, 2006)
"Resilience is the ability of a city to absorb disturbances while maintaining its functions and structures."	Understanding the notion of resilience in spatial planning: A case study of Rotterdam, the Netherland (Lu and Stead, 2013)
„This notion can be translated into a more operational understanding expressed in the definition of the following four risk reduction measures:measures to reduce or avoid hazards; measures to reduce the susceptibility of the affected location to withstand hazards; measures to improve post-disaster response mechanisms and structures; measures to improve post-disaster recovery mechanisms and structures."	Planning for climate change in urban areas: From theory to practice (Wamsler et al., 2013)
"Smart City is defined as the concept of a city that uses ICT to increase citizens' awareness, intelligence, well-being, as well as community participation in the face of pressures, shocks and dangers. To be able to survive, to adapt, to be tough and capable of transformation for the community to achieve a higher quality of life and environment that is sustainable in the face of future uncertainty."	Redefining smart city concept with resilience approach (Arafah and Winarso, 2017)
"Urban resilience is the capacity of a city and its urban systems (social, economic, natural, human, technical, physical) to absorb the first damage, to reduce the impacts (changes, tensions, destruction or uncertainty) from a disturbance (shock, natural disaster, changing weather, disasters, crises or disruptive events), to adapt to change and to systems that limit current or future adaptive capacity."	Urban resilience: A conceptual framework (Ribeiro and Gonçalves, 2019)
"In the urban context, the authors define "resilience" as the potential for a city to thrive as a center of human habitation, production, and cultural progress despite challenges such as climate change, population growth, and globalization."	Smart Resilience City As An Approach To Improve Disaster Risk Reduction (Samir et al., 2023)

As in the mentioned disciplines, there is no single definition of Smart City resilience. This is due to different fields (e.g. environmental or social) addressing the issue from different perspectives. This broad perception of the issue has resulted in the development of a number of indicators that authors have used to characterise and potentially assess Smart City resilience (Ha-Mim, 2024; Patel and Nosal, 2016; Taghizadeh, 2015). However, most of the methods correspond to a conceptual framework focused on sustainability assessment rather than a quantitative assessment of the urban system.

Since the Smart City can be seen as a system (Bonnes et al., 1990), which is made up of various interconnected infrastructural elements, the definition of resilience, which is related to the issue of critical entities, comes into play in this context. According to the European Council and Parliament Directive (2022), the term resilience is defined as "the ability of a critical entity to prevent, protect against, respond to, withstand, mitigate, absorb, adapt to and recover from incidents". When this definition is confronted with the area of critical infrastructure, it is evident that both approaches are determined by similar factors (see Figure 1).

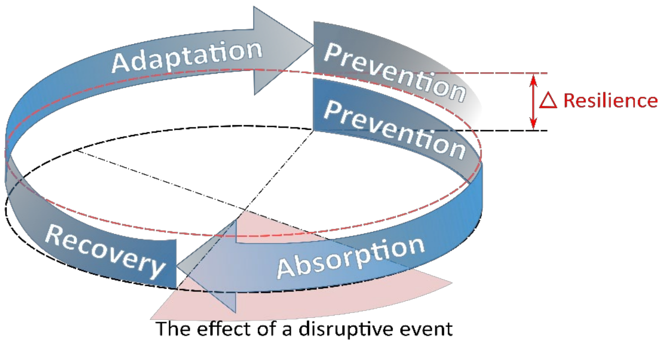

Figure 1: Critical Infrastructure Resilience Cycle (Rehak et al., 2018)

Figure 1, illustrated above, presents resilience in a cyclical process, where the difference (i.e., Δ) between the original and new levels of resilience is perceived as a measure of resilience enhancement. The first phase of the cycle reflects the readiness of the system in the context of possible incidents, i.e. the readiness that is the resulting state of prevention. At the moment of occurrence of a possible incident, the system enters the second phase. This phase is referred to as absorption, the essence of which lies in the robustness or absorption of the potential impact of a given incident. Subsequently, after the end of the incident, the recovery phase occurs, which expresses the ability of the system to restore its operation to its original state. The last phase of the cycle is called adaptation, which expresses the ability of the system to adapt to a repetition of an incident that has already occurred. (Řehák et al., 2018)
Based on the above, it can be stated that the phases that represent the cycle of strengthening the resilience of critical infrastructure can also be applied to the issue of Smart City resilience. Since the unambiguous definition of the factors determining resilience is a key prerequisite for assessing and subsequently strengthening resilience, the following sub-chapter is devoted to defining the factors determining Smart City resilience.

3. Smart City resilience factors

Defining resilience factors can be based on two main approaches. The first approach is methodologically based on indicators characterizing Smart City resilience. In this case, resilience is determined by four core areas which are institutional, social, economic and physical in character (Giffinger et al., 2007; Nam and Pardo, 2011; Jucevicius et al., 2014; Patel and Nosal, 2016; Khatibi et al, 2021). These areas, in turn, include a myriad of possible indicators. As an example, Sharifi and Khavarian-Garmsir (2023) identified a total of 98 indicators. Individual areas and their possible indicators are illustrated in Figure 2.

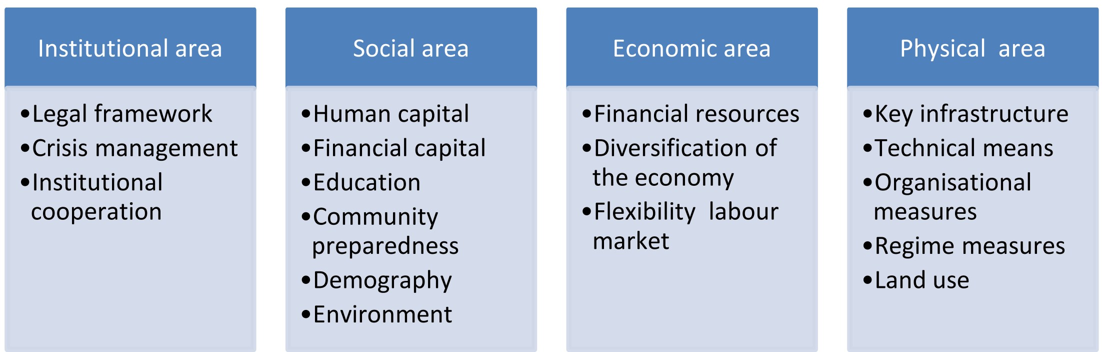

Figure 2: Indicators characterizing Smart City resilience

The first area of Smart City resilience is the institutional area, which is the organisational structure and mechanisms. This area is mainly determined by the following indicators: legal framework, crisis management or institutional cooperation between government and non-government entities (Ttadtaghizadeh et al., 2015). The second area of resilience is the social area, which is determined by human and financial capital, education

and community preparedness (Cutter et al.,2010). Then there is the population itself, or its demography and environment. Another indispensable area which characterises the issue of Smart City resilience is that of economic resilience. Within this area, financial resources are a determining factor, which signifies the ability to cope with costs incurred not only as a result of a crisis (Labaka et al., 2014; Tonn et al., 2016). Other possible indicators are the diversification of the economy, i.e. the expansion of the range of economic activities and investment in different areas, or the flexibility of the labour market. The last area in the context of the problem addressed is the so-called physical area, which focuses not only on key infrastructure elements, such as transport accessibility, but also on technical means, along with organisational and regime measures to increase the physical resilience of these infrastructures or land use (Lovecek et al., 2010; Hillier, 2012).
The second approach is based on factors determining the resilience of critical entities. In this case, resilience is determined by four components, which are resistance, robustness, recoverability and adaptability (Rehak et al., 2024; Sharifi, 2022). These components are then determined by the individual variables (see Figure 3).

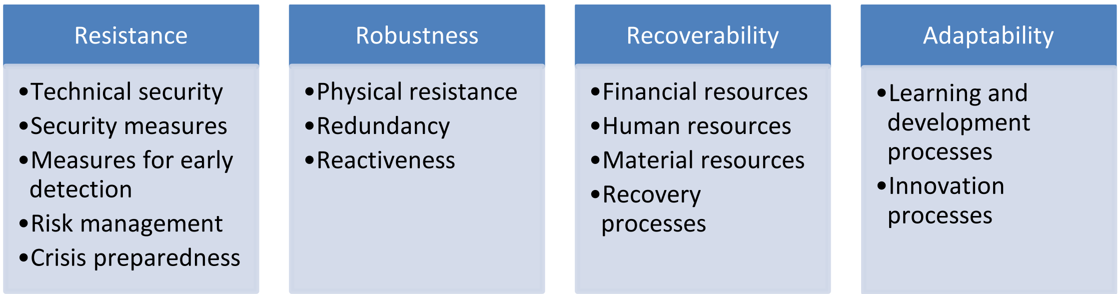

Figure 3: Factors determining the resilience of critical entities

The first component, i.e. resistance, is determined by a total of five variables of a preventive character (Rehak et al., 2022). The first variable of resistance is technical security. This variable is characterized as a set of technical measures for both monitoring and physical protection of the elements in the system in relation to the possible impact of anthropogenic or naturogenic threats (Kampova et al., 2020). The next variable is security measures, which are defined as a set of organizational or regime measures for both monitoring and physical protection of the elements in question. In relation to these variables, the following variable is defined as a set of technical monitoring measures for early detection of a possible incident (Rehak et al., 2019). The penultimate variable, risk management, is defined as the processes associated with the specification of scenarios of potential incidents and the timely assessment and management of risks (ISO 31000, 2018). These risks can be associated with both internal processes and the external environment (Bernatík et al., 2013). Subsequent crisis preparedness is then defined as the ability of a Smart City to prepare for a potential incident and the execution of follow-up security measures through analytical-planning documents (Hassankhani, 2021).
The first variable of the second component, robustness, is physical resistance. It expresses the ability of a given system element to withstand potential incidents using its material and structural resistance (Rehak et al., 2019). Furthermore, robustness is determined by what is known as redundancy due to the potential disruption of the performance or part of a given element (Spaans and Waterhout, 2017). In the context of this component, next in line is the time necessary to activate protective measures or to prevent the spread of consequences caused by a potential incident, i.e. reactiveness (Rehak et al., 2019).
The penultimate component of Figure 2 illustrated above represents recoverability. This component is determined by a total of four variables. In the context of financing the recovery of elements in the event of a potential incident, financial resources become one of the indispensable variables of recoverability (Brugmann, 2012). Other indispensable variables include the availability of human resources (Martin, 2015) along with the necessary skills and the availability of components (Huang et al., 2021) that can be utilised to repair or replace damaged/destroyed elements. Last but not least, there are also so-called recovery processes (e.g., contingency plan) that support rapid recovery of the required element performance (Cimellaro, 2016).
The last component, i.e. adaptability, is determined by processes that support in particular the knowledge, skills or attitudes of people within the system, i.e. learning and development processes (Rehak et al. 2019). Furthermore, the so-called innovation processes that support science, research and implementation of security measures are an important variable in the context of this component (Ribeiro and Gonçalves, 2019).

4. Conclusion

The transformation of so-called traditional cities into Smart Cities is an inevitable step in response to the dynamic development of technology and the increasing demands of the human population. However, the adoption of this concept to improve the quality of human life carries with it threats that may have negative impacts, especially on infrastructure that is considered critical due to its importance.
Although many Smart Cities have already adopted the concept of resilience to protect themselves, there are some shortcomings in this concept. One of the main problems is the inconsistency of the interpretation of the term resilience, mainly due to its adoption from several scientific disciplines. Secondly, the ambiguous determination of resilience factors, which represent the basic starting point for assessing resilience, is at issue. Based on the above facts, the paper encourages the adoption of a uniform definition of resilience in the context of the Smart City. It then proposes two approaches that can be used to determine the basic principles of the concept. The first is an approach based on indicators characterizing Smart City resilience. In contrast, the second of the proposed approaches is based on factors determining the resilience of critical entities, which take into account the so-called cycle of resilience. Since the presented approaches are currently in the research phase, it is necessary to further address this issue, especially the assessment of Smart City resilience.

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