1.10

SMART URBAN RESILIENCY CONCEPTS AND GOALS

How Can Cities Become Smart but also Sustainable and Resilient

Shabtai Isaac, Miquel Casals, Silvio Carta and Blanca Tejedor

Abstract

As urban complexity grows and societal challenges are increasingly complex to address, urban resilience becomes a key factor to enhance our cities. This is particularly relevant when cities are analyzed under the lens of smart approaches to urbanism and Artificial Intelligence (AI) and data-driven city models. The adoption of urban resilience approach leads to communities with a better quality of life and improved environmental conditions toward a general sustainable development of cities.

This chapter addresses the notion of urban resilience through the concepts of smart, data-driven, and sustainable cities. As a multi-faceted notion, urban resilience is broken down into three complementary approaches. First, urban resilience is presented as a quantifiable entity, discussed through advanced spatial approaches using AI, cyber security, and Machine Learning (ML) techniques. This part also includes the distinction between physical and digital elements of community resilience. Second, it is considered in its more original sense, that of response to extreme events in lifelines conditions with examples involving Geographic Information Systems (GIS), Building Information Modeling (BIM), and network analysis approaches. Finally, urban resilience is considered more technically a concerted approach to react to climate change/action, and natural disasters where new technologies and infrastructure management procedures are needed. Each part is supported by practical examples to help readers understand concrete applications in spatial terms.

Through this three-pronged approach, this chapter proposes a possible definition of urban resilience, focusing on ways in which cities can improve on their urban performance, with the desire to provide strategies and solutions for urban problems to provide a higher quality of human life.

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Urban Resilience

In this chapter we introduce the concept of urban resilience in smart cities, discussing its goals and relevant characteristics. In particular, we address the question of how cities can become smart, sustainable, and resilient through a holistic approach.

In general terms, resilience is considered in this context the ability of urban systems to absorb external changes that is changes originating outside of the system itself. This definition draws from the more general description provided in the 1970s by Holling (1973), as well as more recent studies where resilience is contextualized within the realm of smart cities (e.g., Ribeiro and Gonçalves, 2019; Sharifi et al., 2022). The idea of smart cities implies a level of interconnectedness and networks within the urban context facilitated by (digital) technologies, as suggested by many authors, including Cugurullo (2018), Kitchin (2018), and Ferre-Bigorra et al. (2022). We elaborated on these notions further in first section.

This chapter is structured in three parts, where we gradually discuss the measurement, the analysis, and the management of urban resilience. In each part, we describe how the proposed approach addresses both tangible, physical, and technological aspects, as well as intangible, service-based, and procedural aspects.

The first part of this chapter focuses on quantitative aspects of resilience, explaining the metrics at play in both design and urban analysis. The second part focuses on a qualitative assessment of resilience. Through an in-depth analysis, we explain how the resilience of urban lifelines can be assessed in detail and increased to ensure an adequate response to extreme events. Finally, the third part focuses on the management of resilience, explaining how this can be monitored and controlled to better cope with climate change and natural disasters.

Measuring Resilience

Resilience as a Qualitative and Quantitative Framework

There are a large number of studies that characterize urban resilience as a qualitative phenomenon. In the context of urban studies, the term *resilience* can be quite generic and used in many different ways depending on the focus of the study. Bueno et al. (2021) supported that studies on urban resilience are certainly on the rise and can be clustered around cognate areas such as socio-economic and cultural studies, local governance resilience initiatives, and more generically research frameworks and review studies (Bueno et al., 2021:5–10). A quite general definition is provided by Wang et al. (2018), as the comprehensive ability of an urban complex system made up of several subsystems to take in, adapt to, and recover from a disruptive event. This latter can be intended not only as a physical disruption (natural disaster) but also as a social, financial, or health-related issue (e.g., COVID-19). The study of resilience is commonly related to a framework of reference that determines its characteristics. For example, resilience to disruption provoked by earthquakes is usually considered within the context of physical environments.

As the attempt to define urban resilience in a widely shared context can be a daunting task, most studies to date have made use of a framework (or a combination of frameworks) that considers a range of elements, from sociocultural to economic. The Oxfam GB Multi-Dimensional Approach to Measuring Resilience (Hughes and Bushell, 2013), the City Resilience Index (CRI), developed by ARUP and the Rockefeller Foundation (2014),

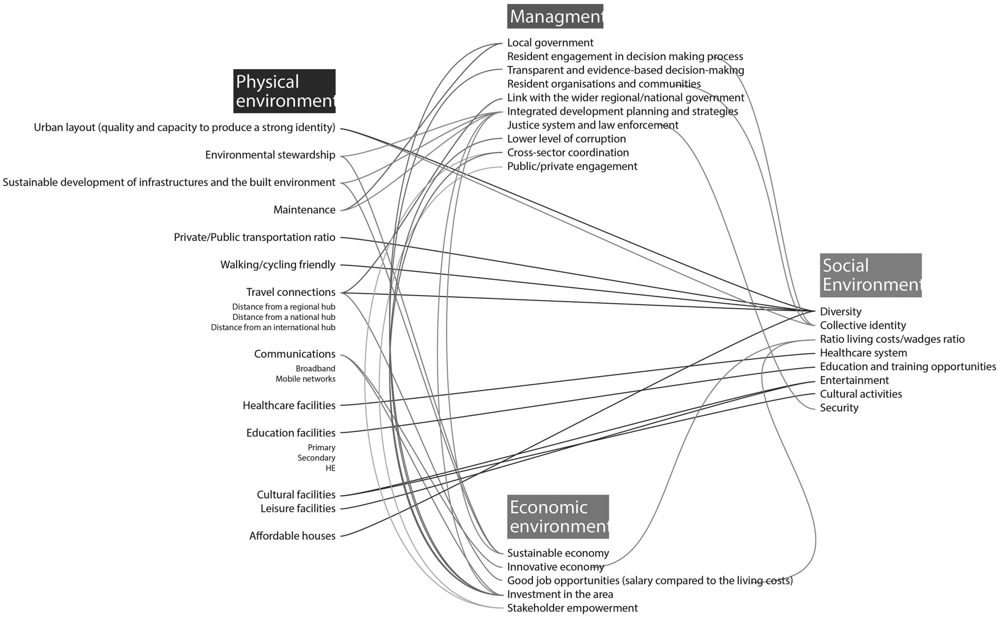


Figure 1.10.1 Mapping of the four categories and sub-elements.

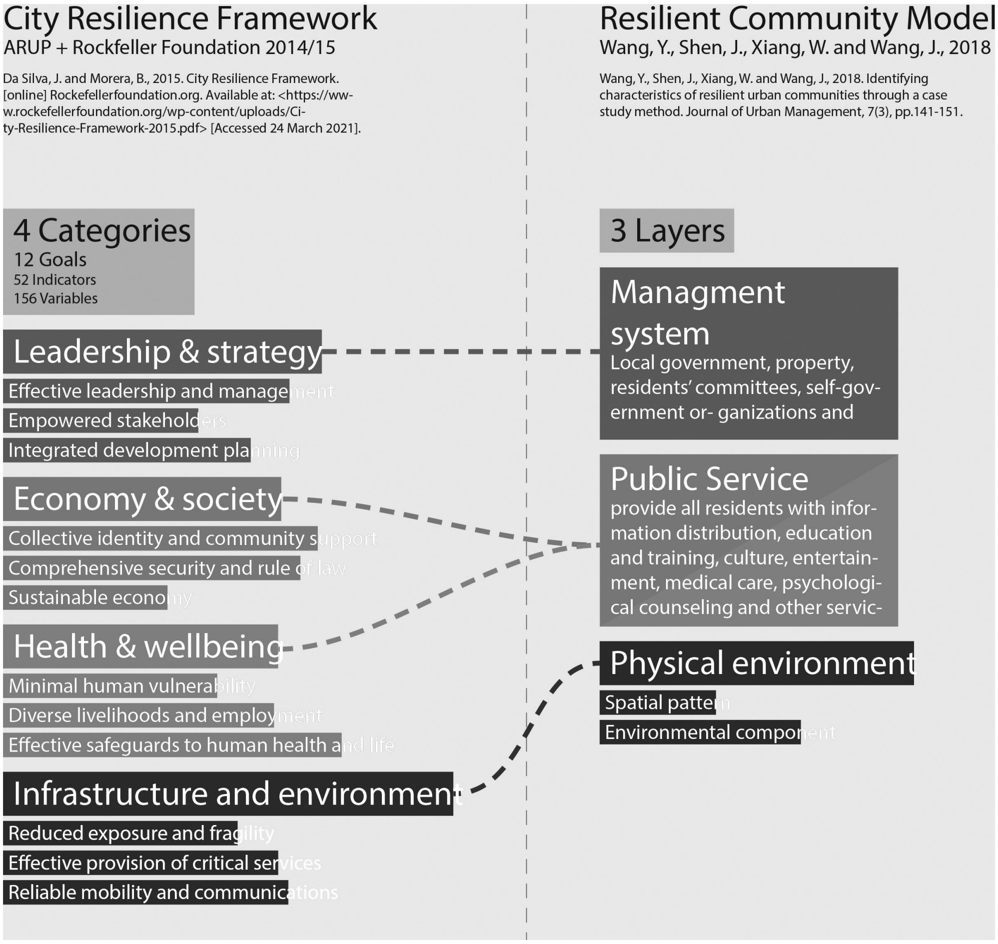
Source: Carta et al., 2021. Diagram by L. Pintacuda.

and the UK Measuring Resilience Report (Sturgess, 2016) are all successful examples of such an approach. These frameworks, which are indicator and method-based, are generally beneficial for comprehending and contextualizing specific geographic, sociopolitical, and urban issues.

In previous studies (Carta et al., 2021), we reviewed several existing frameworks, identifying as a result four main categories that encompass several recurring elements that can help define urban resilience. The categories identified are Social Environment, Economic Environment, Physical Environment, and Management and are summarized in Figure 1.10.1, along with several subcategories that emerged from the literature. In particular, it is worth noting that the two main sources for the development of the mapping we developed are ARUP and Rockefeller Foundation (2014) and Wang et al. (2018) where layers of constituent parts are identified. The correspondence between the two main sources is illustrated in Figure 1.10.2.

Physical and Non-Physical Elements of Community Resilience

The categories summarized in Figures 1.10.1 and 1.10.2 could be easily distinguished by tangible and intangible factors. The majority of elements under Management, Social Environment, and Economic Environment could be regarded as non-physical (e.g., collective identity, job opportunities, and local justice systems). However, all of them can be measured in one way or another. As such, they become quantifiable, and they can be more easily related to physical factors. We approached the measurability of resilient factors in Carta



Da Silva, J. and Morera, B., 2015. City Resilience Framework. [online] Rockefellerfoundation.org. Available at: <https://www.rockefellerfoundation.org/wp-content/uploads/City-Resilience-Framework-2015.pdf> [Accessed 24 March 2021].

Wang, Y., Shen, J., Xiang, W. and Wang, J., 2018. Identifying characteristics of resilient urban communities through a case study method. Journal of Urban Management, 7(3), pp.141-151.

Local government, property, residents' committees, self-government or- ganizations and

provide all residents with information distribution, education and training, culture, entertainment, medical care, psychological counseling and other servic-

Figure 1.10.2 Comparison of the two main sources used (ARUP and Rockefeller Foundation, 2014 and Wang et al., 2018). Although using different categories and/or layers, they both focus on the same areas of investigation.

Source: Carta et al., 2021. Diagram by L. Pintacuda.

et al. (2021, 2022, 2023), where we explored the use of proximity, density, and typologies as strong factors that influence urban resilience at the community level. By analyzing the type of building, amenity, or service (e.g., a local primary school or a fire station), along with their distance from the center of the community and their number within certain areas, we are able to evaluate the extent to which a given community is resilient. Quantifying the resilience of an urban community, in turn, allows us to assess elements from the other macro-categories by looking at the individual factors within each category in the context of successful and less successful communities. Clear measurements of urban resilience based on physical elements help to compare, correlate, and infer information about the other intangible elements that characterize that particular community.

Tools for Resilience Measurement

Many scholars have been addressing the idea of assessing and measuring resilience through clear processes and methods. Among many, we include Caputo et al. (2015), Sharifi (2016), Jankovic (2018), and Petrescu et al. (2021) who worked on what can be defined as CRA (Community Resilience Assessment) tools. These studies concentrated on using quantitative frameworks and measures to rationalize urban resilient communities. One of the important issues raised by Sharifi's study (2016) is the fact that CRA methodologies typically do not account for the impact of change and the dynamic nature of resilience (as a response from communities) across time and geographical scales. This relevant point relates to the pivotal importance of a certain amount of uncertainty that needs to be included in any robust urban resilience tool, reinforcing the notion of resilience not as a static configuration, but as a shifting target (Sharifi, 2016:644). A powerful approach to dealing with uncertainties and change over time is through computational methods.

Artificial Intelligence, Machine Learning, and Cyber Security

There have been several studies addressing urban resilience through a computational and intelligent framework (e.g., Leykin et al., 2018; Yu and Baroud, 2019). An example is the work of Jankovic (2018), where a random grammar technique (Kauffman, 1996) has been employed to calculate resilience at the regional scale. According to Jankovic's approach, binary strings (0/1) represent both raw materials and the processes that transform them into processed resources. Random grammar rules govern the connectivity between the agents and the binary string transformations, which are carried out by models of artificial agents (Jankovic, 2018:4). In a recent study (Carta et al., 2022), we demonstrated how computer vision can be used to calculate urban resilience of any community in the world. The method uses a classifier that has been trained with a large number of satellite images to be able to recognize urban elements (e.g., a building from a park). Once the Artificial Intelligence (AI) model recognizes key typologies, the resilience of a certain community is calculated using a number of parameters that include proximity, distances, and redundancy of the typologies in the area.

Smart technologies are increasingly employed in cities to improve performance, safety, and economy at both local and regional scales. As cities become smarter, the risk related to urban data increases. Specifically, as citizens' information and infrastructure mechanisms are increasingly data-field (think of smart grids, self-tracking, urban sensors, etc.), cyber security becomes paramount. This notion is clearly encapsulated by the work of Andrade et al. (2021) on cyber-resilience, intended as the city's preparedness for a crisis, responsiveness, and capacity to reinvent its information and communication technologies (ICTs) structure in the face of persistent stress and severe interruptions (Andrade et al., 2021:189). In the next section, we will discuss the implications of such measurements and analysis and their relevance for urban resilience.

Analyzing Fragility and its Implications

Challenges in Analyzing the Fragility of Urban Systems

Urban infrastructure systems are essential for cities worldwide, but they are complex and continuously evolving with population growth and changing needs. Assessing the fragility of such critical infrastructure systems during extreme events is of vital importance. The continued functioning of urban systems when an extreme event occurs is determined by their structural integrity and affected by other critical utilities on which they depend. An analysis of this fragility requires an assessment of the locations where the infrastructure is likely to be structurally damaged, as well as of the impact of cascading failures that may occur in other interdependent infrastructure systems. Such an assessment is challenging to perform due to the significant complexity of the interdependent systems, and since the extreme event itself is difficult to define given that it has rarely, if ever, occurred.

Two types of analyses have been developed to assess the fragility of critical infrastructures under extreme events: reliability analysis and vulnerability analysis (Johansson et al., 2013). Reliability analysis aims to calculate the probability of systems performing under certain hazards and threats (Faturechi and Miller-Hooks, 2014). It has been criticized for relying on quantitative estimates that are based on limited knowledge and are therefore often inaccurate since they refer to low-probability, high-consequence events that are difficult to estimate (Johansson et al., 2013). Vulnerability analysis, on the other hand, aims to assess the inherent ability of a system to cope with certain hazards (Faturechi and Miller-Hooks, 2014). It seeks to determine the system's expected behavior under extreme circumstances by systematically identifying the impact of strains on the system, revealing its weaknesses. This can be done, for example, by simulating a specific scenario. However, it leaves open the question of how the simulation of certain scenarios will allow the "critical functionality" of a system to be identified if it is faced with unknown threats (Ganin et al., 2016). It may be impossible to consider and quantify in practice all the relevant events that may affect networked infrastructure systems of a complex nature (Linkov et al., 2014).

Many urban infrastructure systems are highly interdependent. Consequently, when a failure occurs in one system, this may result in additional failures in other systems—or "cascading failures". Such interdependencies must be included in an assessment of the fragility of any such system. However, cascading failures are very difficult to evaluate using conventional methods, since there is an essentially infinite number of potential operating contingencies and system changes that need to be considered (Eusgeld et al., 2011).

A Practical Approach for Analyzing Fragility

To provide an effective approach for the assessment of the fragility of urban infrastructure systems, a method needs to be developed that will reduce the complexity of the required analysis (Vatenmacher et al., 2022). To simplify the analysis process, it is essential to first focus on the relevant data to be analyzed rather than diving into exhaustive data analysis, which may include irrelevant information that is challenging to collect. An effective alternative approach is to reduce the amount of data used in the analysis by avoiding non-critical and redundant elements. This can be achieved by concentrating on the specific needs of essential end-users and quantifiably determining the circumstances under which the infrastructure systems supporting their activities might fail to meet those needs.

Such an assessment requires a definition of the impact of extreme events on the infrastructure system in terms of Levels of Service (LoS): a quality measure of the performance of the system analyzed. The complexity of an analysis of the fragility of urban systems in the highly unpredictable environment of extreme events can be reduced by considering solely the threshold where these systems no longer provide minimal LoS. In this way, the analysis of low-probability and high-impact events can be avoided. This is important in practice,

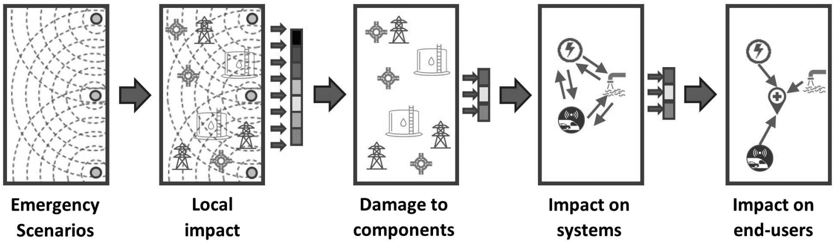


Figure 1.10.3 The conventional process for analyzing the fragility of urban systems.

Source: Shabtai Isaac.

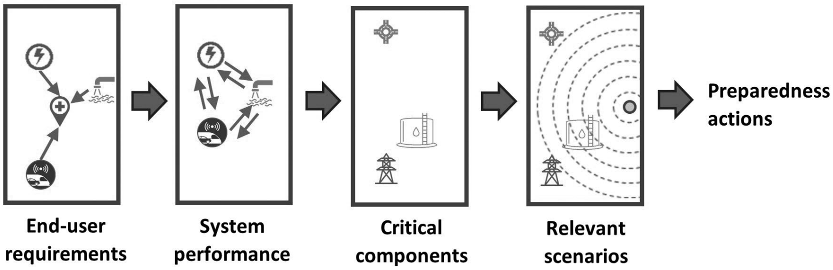


Figure 1.10.4 Proposed reversed process.

Source: Shabtai Isaac.

since historical data is often not available for such events, and their implications are consequently difficult to analyze. These difficulties are reduced by limiting the assessment to specific threshold scenarios whose probability is higher, yet which will lead to unacceptable outcomes in terms of insufficient LoS.

The proposed approach can be implemented by reversing the process through which the fragility of urban systems is usually analyzed (Figure 1.10.3). This is achieved by starting the analysis at the point where such analyses currently end, namely, the end-user and its requirements (Figure 1.10.4):

1 In the first stage, the required functionality of the systems is determined. The end-user requirements are defined that need to be ensured after an extreme event has occurred. Following this, the required performance is defined of other urban systems required to support the end-user's requirements, and the components in each system that are critical for fulfilling these requirements are identified. Then, the minimal LoS that each previously identified critical component needs to provide is defined.
2 In the second stage, the level of damage to each critical component that will prevent the minimal LoS from being provided is determined.
3 In the final stage of the analysis, scenarios are identified in which such damage will occur to the critical components, and the possibility of these scenarios is assessed. If the possibility of the occurrence of such a scenario is found to be significant, preparedness actions will need to be planned and executed to prevent the failure of critical components.

By reversing the process in which the fragility of urban systems is analyzed, its complexity is reduced in all respects—organizational, informational, and analytical. By considering only the threshold scenarios, the scope of the analysis is narrowed and irrelevant data such as non-critical elements can be ignored. Consequently, the organizational and informational resources that are required to carry out the analysis are reduced, and additional analyses can be carried out once the systems are changed.

Managing Resilience

The concept of resilience and the instruments for its evaluation have become a key topic in the last years, in response to the concerns about the increase and severity of disaster events. Within the dimension of urban infrastructure, three action fields can be highlighted: (i) social resilience; (ii) energy resilience; and (iii) thermal resilience. However, the assessment of most of them is still ongoing, since the number of requirements to be observed depends on the damage level and the possible scenarios to consider. A brief explanation of the aforementioned aspects is reported below.

Social resilience is defined as the community response to a disaster as well as its post-recovery. Kwok et al. (2016) proposed two categories of indicators, structural and cognitive. The first one considers the adaptability to embrace a change, community inclusiveness and health care capacity, food provisioning capacity, transportation access, communication capacity, leadership, and social support. The second one is related to access to economic resources, critical awareness, collaborative decision-making or collective efficacy, problem-solving policies, disaster management planning, diversity of skills, knowledge of community assets, knowledge of hazard consequences, robust community spaces, and social networks.

The indicators of energy resilience can be categorized into three domains. The first one corresponds to building characteristics, namely, disaster-resistant building, age of building, materials and construction, and maintenance of households (Osei-Kyei et al., 2023). The second domain pertains to renewable energy and the capacity to share and generate at least 5% of electricity (Feldmeyer et al., 2019). The third one is the reliability of ICT networks, which can be measured through the percentage of risk areas with monitoring, and alert systems integrated into the community, the average number of electrical interruptions per customer and year, upgrades of critical infrastructure, and the number of days that city fuel supplies could maintain essential household functions, etc. (Sharifi, 2016).

For thermal (and heat) resilience, the indicators can be classified into seven categories as follows:

i Time to a critical level. This considers active and passive survivability (Katal et al., 2019; Homaie et al., 2021; Siu et al., 2023).

ii Maximum level of thermal stress, which refers to the maximum values of indoor and outdoor air temperature, daily discomfort index (DI), and Predicted Mean Vote (PMV) (Sailor et al., 2014; Baniassadi et al., 2018; Rajput et al, 2022; Siu et al., 2023).

iii Time to exceedance, related to determining the period in which the indoor thermal comfort requirements are not accomplished given an event, considering as metrics: occupant hours lost thermal (OHL), heat index hazard hours (HIHH), PMV exceedance hours (PMVEH), the cumulative percentage of time above critical temperature, hours of exceedance (HE), HE upper limit temperature (HEULT), daily weighted exceedance

(We), percentage of occupied hours outside the range (POhOR), and number of consecutive days exceeding threshold maximum temperature (Pyrgou et al., 2017).

iv Time integral to exposure, which includes metrics such as unmet degree hours (UDH), standard effective temperature (SETUDH), and the weighted unmet thermal performance (WUMTP) (Homaei and Hamdy, 2021, Sun et al., 2021, Siu et al., 2023).

v Overheating intensity, defined by the response parameters like indoor overheating degree (IOD), ambient awareness degree (AWD), overheating escalation factor (OEF), and percentage of overheating hours (OH) (Baniassadi et al., 2018; Sun et al., 2021, Siu et al., 2023).

vi Outdoor comfort, which involves the indicators related to the public space surrounding the housing, such as outdoor neutral thermal threshold (NTT), outdoor critical thermal threshold (CTT), spatial heat resilience index (SHRI), and universal thermal comfort index (UTCI) (Sharifi et al., 2016).

vii Autonomy of the systems in a power outage, which refers to indicators such as building heat performance index (BHPI), gain utilization factor (GUF), hours of safety in free running mode, thermal autonomy (TA) and ventilation autonomy (VA) with only passive means (Katal et al., 2019).

All the action fields are correlated among them. Mavrogianni et al. (2014) mentioned that elderly people are less likely to adopt ventilation strategies in heat waves, and this could lead to amplifying the exposure to indoor air pollutants or to increasing temperature and humidity levels at home. Several studies indicated a strong relationship between the deterioration of human health (i.e., dementia, schizophrenia, diabetes, respiratory, and cardiovascular diseases) and very high outdoor temperatures (Escandón et al., 2022). Along this line, Baniassadi et al. (2018) demonstrated that the age of the building is also highly correlated with the indoor overheating rate. In less than 6 hours of power outage associated with a heat wave, older construction houses reach the DI thresholds, and the overheating values are estimated between 56 and 73 degree-hours, while new buildings can keep indoor environmental conditions. Considering that the discomfort hours could reach 36% higher values in Southern European residential stock in 2050 (i.e., Greece and Spain) (Escandón et al., 2022), the analysis of the main thermal metrics should focus on real-time monitoring. If several future scenarios are analyzed, predictive controls of building facilities based on weather forecasts could help in the adaptation of users' environments to extreme events and reduce the damage level.

It should be noted that for the energy resilience domain, the measurement level corresponds to the community, while thermal resilience refers to a building or to the public space where the housing is located. The resilience of buildings should be considered from the thermal to the energy and social domains. For example, good monitoring and control of the percentage of OH for different renovation variants at the room level could lead to lower energy consumption values and avoid an excessive operation of the energy production systems. This in turn could help to reduce energy interruptions per customer per year as well as the maintenance tasks or replacement of machinery. Hence, if building environmental conditions could be guaranteed before the occurrence of heat or cold waves, the risk of mortality or diseases of building users could be minor.

Conclusions

Summarizing, urban resilience in the context of smart cities is characterized by a degree of measurability, through quantitative approaches and increasingly robust tools (first section), elements of fragility within critical infrastructure systems, and the balance of each element (second section), and the need for a holistic approach and unification of criteria in the design of indicators for effective management of resilient communities in the built environment.

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