International Journal of Disaster Risk Reduction 75 (2022) 102970

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

On the relation between ‘resilience’ and ‘smartness’: A critical review

Juan Sebastián Cañavera-Herrera [a,d], Junqing Tang [b,d,*], Timea Nochta [c,d], Jennifer M. Schooling [d]

[a] AECOM UK. Sustainable and Resilient Cities Team, AECOM, Aldgate Tower, London, E1 8FA, United Kingdom
[b] School of Urban Planning and Design, Shenzhen Graduate School, Peking University, 518055, China
[c] Institute of Local Government Studies, School of Government, University of Birmingham, United Kingdom
[d] Centre for Smart Infrastructure and Construction, Department of Engineering, University of Cambridge, United Kingdom

A R T I C L E I N F O

Keywords:
Smart city
Resilience
Sustainability
Digital technology
Data security

A B S T R A C T

Cities continue to face significant challenges that test their capacity for resilience. With the development of smart cities, there needs to be a better understanding of how the introduction of smart technologies will affect urban resilience. To address this issue, this article presents a critical review of the literature on smart cities and smart technologies focussing on representations of resilience. The findings reveal that discussing resilience in relation to smart city components of the data layer, digital technologies and the physical city can provide some degree of clarity despite the existence of a multiplicity of definitions and interpretations. Furthermore, the analysis indicates that the nature of relationships between ‘smartness’ and ‘resilience’ remains contested, and largely dependent on the perceived role of digital technologies in resilience-building processes. This in turn is influenced by *how* these technologies are used and what the *intention* and *expectations* are in relation to their use. In order to address these issues, we conclude that further interdisciplinary research, extending to the physical, social and environmental systems of cities, is needed to better understand the relations between smartness and resilience.

1. Introduction

Cities will continue to face significant challenges during the 21st century as a result of changes in demography, politics, the climate, the global economy and technology. These changes will likely increase the demand for housing, services for ageing populations, the sustainable sourcing of food, water and energy, resilient infrastructure, and improved organisational and institutional arrangements [1–3]. To deal with these emerging challenges, different urban development models have been proposed in recent years, including eco-city, green city, sustainable city, liveable city, resilient city, smart city or a combination of these (e.g. resilient smart city) [4–6]. The concepts of sustainability, resilience and smartness have become key to urban planning and management theories and practices. They represent idealistic visions, promoted by influential organisations including the United Nations, the Rockefeller Foundation and the European Union, for which cities must aim in order to remain attractive to businesses and citizens, and competitive in the globalised economy [7–9]. Despite their influence on the planning and management of cities, these concepts remain fuzzy, contested and vague. This lack of conceptual clarity also leads to difficulties with assessing and evaluating the interrelations among resilience and

* Corresponding author. School of Urban Planning and Design, Shenzhen Graduate School, Peking University, 518055, China.
E-mail address: junqingtang@pku.edu.cn (J. Tang).

https://doi.org/10.1016/j.ijdrr.2022.102970
Received 23 October 2021; Received in revised form 11 April 2022; Accepted 14 April 2022
Available online 19 April 2022
2212-4209/

smartness, and sustainability [2,3,10–13]. In turn, this has consequences for the purposeful utilisation of emerging technologies to improve sustainability and resilience in cities.

The smart city agenda represents attempts to deal with large-scale environmental and socioeconomic challenges through technology-driven urban retrofit and development building mainly on information and communication technologies (ICTs) [3,10,13,14]. Such attempts most often feature sensors, big data, Internet of Things (IoT), data-driven decision-making and automation, and may even extend to enhancing human and social capital with ICTs [10,12]. In other words, "*the notion of the 'smart city' encompasses a broad and loosely defined toolkit of technological 'solutions' and policy interventions aimed at: (a) implementing urban technologies to monitor urban systems and improve their efficacy through real-time monitoring and 'big data' analytics; and (b) urban development and capacity-building through the generation of technology-enabled human capital*" [15]:209).

A review of the various existing smart city definitions and classifications however shows that mainstream interpretations do not include or directly refer to 'resilience' as a core factor in making cities smarter [3,10,11,13]. This is a serious oversight in a rapidly urbanising and digitalising world in which climate change, mass migration, natural disasters, pandemics, and unprecedented pressure on the provision of social services for an ever-growing urban population will test the capacity of urban systems to thrive – in other words, their resilience. 'Resilience' can be understood broadly as "*an endowed or enriched property of a system that is capable of effectively combating (absorbing, adapting to or rapidly recover from) disruptive events*" [16]:91). Furthermore, with the development of smart cities,

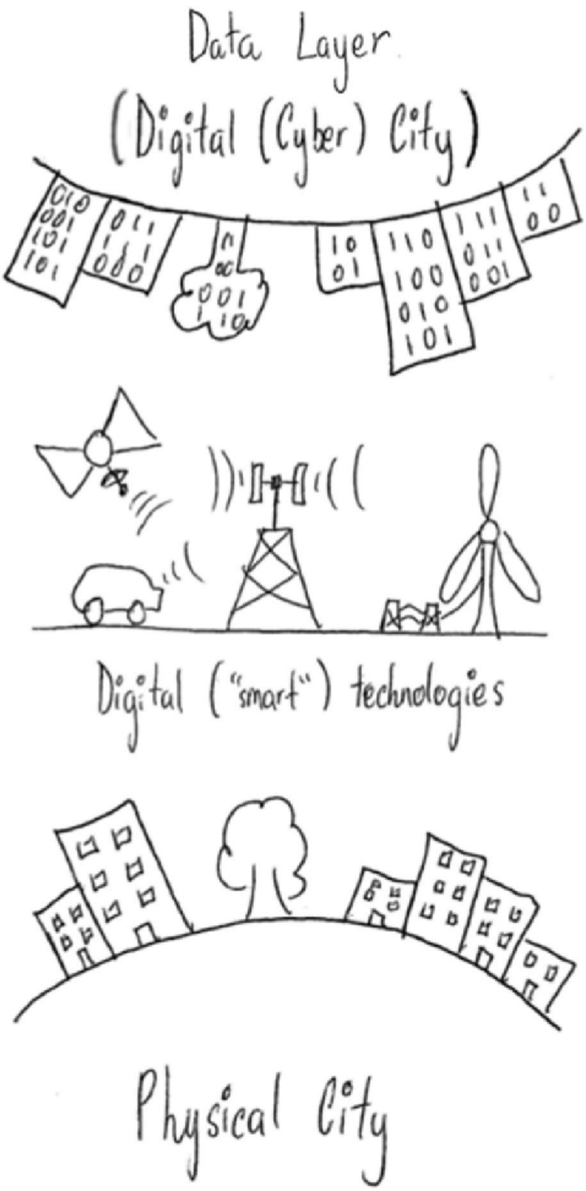


Fig. 1. The basic conceptual components of a smart city.

there is an acute need for a better understanding of how the introduction of additional layers of technology into urban systems will affect the complexity of the urban landscape, and accordingly, the ability of a city to establish effective resilience to such challenges.

This paper investigates the interrelations between the concepts of 'resilience' and 'smartness' in city planning and management through a critical review of the academic literature on smart cities and digitalisation between 2015 and 2020. Assessing the implications of smart city digital technologies to urban resilience is particularly timely and important due to the ever-increasing popularity of 'smartification' as a way of modernising cities and city systems in response to contemporary challenges. Addressing a significant gap in research, our analysis expands on earlier reviews that are, to a large extent, limited to understanding the implications of 'smartification' on the physical city and its inhabitants (see Arafah, Winarso, and Suroso [11]; Baron [17]; or Papa et al. [12]. Looking beyond the physical-material dimension of the city, we investigate how the concept of 'resilience' appears, and is operationalised, in the context of digital technologies and the data environment resulting from their implementation. The main contributions of this paper can be summarised as follows:

- This paper provides a timely critical review that analyses how the literature at the intersection of smart and resilient cities defines and uses these two urban development concepts. As such, it can be used as a consultation paper for further research.
- Our review confirms that various definitions of resilience exist in the smart city and smart technologies literature. In order to make sense of multiple definitions, we propose a simple, yet robust, conceptualisation of the 'smart city' and classified the articles reviewed according to their main focus on different components of the smart city. We define these components as the 'data layer', 'digital ('smart') technologies' and the 'physical city'.
- The analysis shows that this section of the literature often links urban resilience and smartness through what many authors consider as a more holistic concept: sustainability. We propose the 'Resilience-Smartness-Sustainability triangle' framework to describe the interrelations between resilience and smartness. This framework highlights that resilience is often considered as an element of sustainability, while smartness is perceived as a means to achieve sustainability. This implies that, at least on the conceptual level, the purposeful implementation of smartness to improve sustainability is likely to help to increase resilience – which is part of sustainability. However, this relationship is not straightforward.
- Finally, our analysis underlines the need to appreciate the context-dependence of interpretations of smartness and resilience. Based on the results, we call for interdisciplinary research aimed specifically at studying the contribution of specific smart city digital technologies to resilience-building processes in order to increase the evidence-base and improve our understanding of the relationship between smartness and resilience.

The remainder of the paper is structured as follows. Section 2 presents a conceptualisation of the smart city proposed by the authors that is used to guide the review. Section 3 presents the research questions and the data collection methods used to construct a qualitative database for the critical review of the academic literature on smart cities and digital technologies. Section 4 discusses our findings from the review, with Subsection 4.1 focussing on the interpretations of resilience within the smart cities and digital technologies literature; Subsection 4.2 on the conceptual links between resilience and smartness emerging from the literature; and Subsection 4.3 on the role of digital technologies in resilience building. Based on these findings, Section 5 summarises the most important points and presents our conclusions and recommendations for future research.

2. A conceptualisation of the smart city

In this paper, the authors propose a simple, yet useful, conceptual interpretation of a smart city to guide the analysis presented (Fig. 1). This conceptual interpretation satisfies the definition of a conceptual framework from Jabareen [18]:51) (A conceptual framework is "*a network, or "a plane," of interlinked concepts that together provide a comprehensive understanding of a phenomenon or phenomena")*. This interpretation sees a smart city as being composed of three main components:

1) **The physical city:** the physical city is interpreted in this conceptual vision of a smart city as all the non-digital or 'non-smart' elements of a city. This includes all traditional physical non-digital infrastructure (e.g., traditional roads, water systems, storm water systems, 'non-smart' buildings, etc.), but is not limited to these. Cities are interpreted in this paper as socio-techno-ecological systems; therefore, the physical city also includes the urban communities (and their social systems) and the natural elements of a city (e.g., rivers, parks, green infrastructure, urban animal species, the atmosphere above a city, etc.).
2) **The digital ('smart') technologies:** these are all the technologies that are deployed in a city to make it 'smart'. These include technologies such as ICTs, sensors, and Internet of Things (IoT) technologies. These technologies are used to monitor (i.e., generate useful data from the urban environment), interconnect elements of the physical city (i.e., allow flows of data in the urban environment) or enhance the capacities of the elements of the physical city (i.e., use data for improving urban processes). Some of these technologies are sometimes embedded inside other existing technologies or infrastructure to generate 'smart' versions of them (e.g., 'smart' roads or 'smart' grids).
3) **The data layer:** the data layer can be understood as a digital mirror image of the physical city produced by the data collected by the 'smart' technologies. This mirror image can be called the digital city or the cyber city. The data in this layer includes the data produced in the monitoring of the physical city, in the communications between elements of the physical city and from the analysis of raw data that can be used for improving urban processes (this includes models and information). Data management technologies are also considered to be part of this layer.

In our interpretation, each of the aforementioned layers constitutes a complex system and, in reality, these three layers are deeply intertwined, forming a so-called non-linear system-of-systems.

Another highly-related concept in the field which can be often found co-existing with the smart city is the 'digital twin city' concept [19]. The digital twinning also involves physical, digital, and data components in its definition (i.e., a digital twin city is a virtual replica of the physical city, which is often built upon real-time data and high-fidelity simulations and modelling [20]). However, this should not be confused with the proposed conceptualisation of the smart city as these two city concepts are fundamentally different. Essentially, the smart city concept is higher and broader than the concept of the digital twin city – one can largely interpret the digital twin city as a specific tool that can help to approach smart city problems (i.e., simulating 'what-if' scenarios for achieving evidence-informed decision-making).

3. Research strategy and data collection

The following questions were devised to guide the construction of a qualitative database for a critical review of the literature on digitalisation and smart cities through resilience lenses:

- (Q1) How is resilience perceived and defined in smart city literature?
- (Q2) How are the concepts of resilience and smartness related on a conceptual level?
- (Q3) What is the role of digital technologies in resilience-building processes?

Critical review as a research strategy is widely used in studies aiming to address questions with a broad scope [21]. As Paré et al. [21]:189) state *"these reviews aim to critically analyze the extant literature in a broad topic to reveal weaknesses, contradictions, controversies, or inconsistencies"*. Due to the broad focus of the questions tackled, critical reviews aim at producing relevant hypotheses or models rather than definitive answers to these. They focus on evaluating what is of value from previous bodies of work and offer possible new conceptual development paths [22]. However, critical reviews do not aim to provide a comprehensive and systematic reading of all relevant literature [21–23]. Supporting this critical review, the approach taken to data collection and analysis to address questions Q1 and Q2 are presented in Section 3.1, and in Section 3.2 for Q3.

3.1. Constructing the literature base to address Q1 and Q2

The first two research questions focus on conceptual understandings of the resilience and smartness in the urban context. The database for critical review was constructed via searches using the online databases Google Scholar and Scopus which cover a wide range of literature. Searches were performed using the key words 'resilience' AND 'smart city', with limiting the results to subject areas of engineering, social sciences, environmental science, decision sciences, and Earth and planetary sciences. The review focused on literature published between 2015 and 2020 to ensure that the information collected covers a substantial period and includes full years of records. Additionally, the literature reviewed was complemented with a number of earlier seminal works based on citations (e.g., Wohlin [24]; Ernstson et al. [25]. Of the initial results, 99 papers were identified as relevant for addressing Q1 and Q2 based on a review of titles, abstracts, and keywords. Based on the detailed reading of these initially selected articles, 12 were excluded due mainly to using 'resilience' and/or 'smart city' in their titles, abstracts, or keywords as buzzwords but included no discussion of smart cities, smart technologies and/or their resilience.

The remaining 87 documents were divided into three groups depending on the specific components of the smart city they focused on (see Section 2). Some articles covered more than one component and they were classified according to which component they gave more focus. Using this classification system, 54 documents could be classified as focussing on the resilience of the physical city, 27 documents on the resilience of digital technologies, and 6 on the resilience of the data (produced by digital technologies) in cities. A categorised list of references to the articles included in this review is shown in Table 1.

3.2. Constructing the literature base to address Q3

Addressing Q3 required a parallel literature search with a specific focus on resilience-building and digital technologies. This round of data collection was aimed at understanding how various digital technologies are, or are envisaged to be, used in resilience-building processes in the urban built environment. Searches were performed using the key words 'resilience' AND 'digital technology' in Scopus and Google Scholar, in a similar vein to addressing Q1 and Q2. In addition to the search results obtained this way, further papers were added based on citations (for example, Bailey and Wilson [98]; Yates and Paquette [99]; or Garbett et al. [100]. This approach identified 22 articles which were used to address Q3, as shown in Table 2.

4. Findings and discussion

The findings from our review of the literature on smart cities and digital technologies are introduced in the following three sections: section 4.1 presents the findings relevant to Q1, and sections 4.2 and 4.3 introduce the findings in response to Q2 and Q3 respectively. In each section, the findings of the literature review are discussed and insights are presented based on the analysis of the findings and in response to our research questions.

Table 1
Documents reviewed divided into categories depending on which component of the smart city they focus on.

Resilience of the physical city	Resilience of the smart technologies	Resilience of the data
[4–12,14,15,17,25–65,123]	[66–91,124]	[92–97]

Table 2
Documents identified in the complementary literature search.

Articles discussing the role of digital technologies in building urban resilience
[1,2,98–116,125]

4.1. 'Resilience' in smart cities

Using the classification of smart city components introduced in section 2 (physical city, digital/smart technologies, data layer), the review found that 'resilience' as a property is interpreted differently for each of the three components. These differences are related to the types of threats faced by each component and the focus on protecting either the digital, physical (built or natural environment) or social systems of a city (Fig. 2). The following three subsections present more detailed discussions on how the concept of resilience is interpreted when applied to the different components of smart cities.

4.1.1. Resilience of the data layer

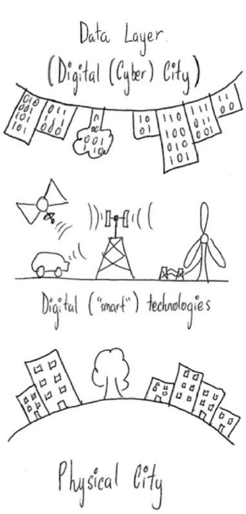
Despite the prevalence of 'big data' and 'data analytics' in smart cities, only a small subset of the surveyed literature focused specifically on the resilience of the data layer (six articles, as listed in Table 1). Some additional articles which concentrate mainly on the physical city or on the smart city digital technologies engage in discussing briefly the resilience of the data layer too, but do not offer new insights compared to the articles classified as focussing on data (for example, Ng et al. [9]; Poncella et al. [83]; Roohi et al. [84] or Yarime [64].

The articles selected for analysis emphasise the threat of cyber-attacks in relation to the resilience of the data layer [92–96]. A variety of different types of cyber-attacks are considered which may lead to corrupting, destroying, stealing or leaking data. Beyond organised cyber-attacks, data corruption can also occur as a result of human error or as part of the normal functioning of the digital equipment over its lifespan [97]. Consequently, resilience in this component of the smart city is predominantly associated with concepts such as security and reliability. Data security is most often discussed in terms of protecting privacy or processing sensitive data associated with critical systems (e.g., infrastructures) in the city. Reliability is associated in this context with data quality (minimising and/or managing data corruption), credibility in terms of trustworthiness, and accessibility.

As a result, a common approach to defining resilience in the context of data in smart cities is to view it as the ability of the data layer to resist deliberate man-made hazards such as cyber-attacks (Gao et al. [94]. According to Boyes et al. [93]:1–2), *"[intercommunicated] systems will need to be designed and built to achieve high levels of resilience, so they continue to operate under adverse conditions. Where this is not possible they should be designed to degrade in a controlled manner that can be readily restored to full operating conditions once any adverse situation is resolved"*. Definitions in the papers reviewed highlight a strong focus on maintaining the functioning of data systems during and after shocks (e.g., cyber-attacks). A notable exception is Hiller and Blanke [96] who propose to conceptualise 'privacy' as a system and analyze it through the lens of resilience theory. They assess the advantages and disadvantages of different approaches (engineering, ecological and socio-ecological resilience) in protecting privacy.

4.1.2. Resilience of smart city digital technologies

The second component of smart cities are the smart digital technologies that interconnect existing systems or generate new data from the physical city and its environment to provide new or improved services to urban citizens. These technologies are at the nexus



Threats	Related concepts	Scope
• Accidental man-made hazards (Human error, Data Corruption, Technological Hazards) • Deliberate man-made hazards (Cyber-attacks)	Resilience is associated with **security** (i.e., privacy, sensitive data) and **reliability** (e.g., data is not corrupt, is accessible, is of good quality)	Digital systems of smart cities.
• Natural hazards • Accidental man-made hazards (Human error, Software Corruption, Technological Hazards) • Deliberate man-made hazards (Cyber-attacks, terrorism)	Resilience is associated with **reliability** (i.e., keeping services like electricity or the internet working in the case of an emergency or a disaster). It is less associated with **security**.	Physical and Digital systems of smart cities.
• Natural hazards • Accidental man-made hazards (Human error) • Deliberate man-made hazards (Cyber-attacks, terrorism) Note: The impacts of hazards can cascade from one component to the other(s).	Resilience of **socio-techno-ecological systems**: • **Urban resilience** (i.e., Social, economic, environmental) • Closely related to **sustainability.**	Physical systems of smart cities.

Fig. 2. Visions of resilience in smart city literature.

between the physical city and the data layer. Therefore, they can be subject to threats from both, including accidental (e.g., human errors) and deliberate man-made hazards (e.g., terrorism) or natural hazards [44,69,73].

Our review revealed three main types of 'digital technologies' that are discussed in the smart cities' literature:

1. Technologies for the Smart (power) Grid [68,70,74–76,78,79,85–87,91].
2. Wireless Sensor Networks and Internet of Things (IoT) technologies [66,67,71,80,82–84,86,89,90]; and
3. Technologies for Smart (Digital) Critical Infrastructures [69,71–73,77,81,88].

These articles emphasise the role of digital technologies in the provision of new or improved services. For example, Vermiglio et al. (2020) explicitly limit their focus to "*the enhancement of service quality to citizens … to increase the level of safety and security of the communities*" (Vermigilio et al., 2020:116). As a result, reliability becomes a key concept associated with resilience in this part of the literature. Reliability in these articles most often refers to maintaining the provision of a service, such as electricity or the internet, in case of an emergency or a disaster. Security remains a concern but to a lesser extent than in the context of data. Instead of being a key focus area, the ability of digital technologies to resist deliberate man-made hazards is discussed as one of several possible hazards to this component of the smart city.

Definitions of resilience found in these articles reflect the heightened focus on its relationship with the concept of reliability. Abreu et al. [66,67] define the resilience of IoT systems specifically as the ability to guarantee the continuity of the services they provide. Poncela et al.'s [83]:154) definition reflects similar considerations by treating the resilience of IoT enabling technologies as *"the ability to deliver service and information that can be justifiably trusted in spite of continuous changes and is in accordance with user requirements and resource constraints"*. Further, Sterbenz [86]:1) defines the resilience of Internet infrastructure as *"the ability of the network to provide and maintain an acceptable level of service in the face of various faults and challenges to normal operation"*.

In addition to the service-delivery-focused definitions, more generic definitions could also be identified in this part of the literature. For example, Jung et al. [76]:1) define resilience as *"the ability of a system to mitigate and rapidly recover from a disruptive event"*. Annaswamy et al. [69]:269) provide the following definition:

> *"Resilience of a system with respect to a class of extreme and high impact disturbances, is the property that characterizes its ability to withstand and recover from this particular class of disturbances by being allowed to temporarily transit to a state where its performance is significantly degraded and returning within acceptable time to a state where certain minimal but critical performance criteria are met"*.

The definitions found to be focused on the service delivery aspect of smart city digital technologies represent interpretations of resilience that correspond mainly to an engineering resilience approach. Engineering resilience *"focuses on a return to the original state of being, minimal fluctuations from equilibrium, and an emphasis on understanding system design and operation in order to increase successes rather than decrease failures"* [96]:346). The more generic definitions of resilience found in papers in this category however highlight a different approach – the ecological perspective of resilience. In this perspective, resilience is seen as *"the ability to absorb attacks and accommodate greater deviations from the starting point without requiring the system to return to the exact central point*" [96]:342). The classification devised by Hiller and Blanke [96] also includes a third approach: socio-ecological resilience. This third approach is more prominent in articles on the resilience of the physical city as discussed in the next subsection.

4.1.3. Resilience of the physical city

The majority of articles included in this review have been found to investigate resilience in the context of the physical city. Key considerations include the potential of smart city technologies in improving the resilience of the physical city, and whether the implementation of new layers of technology and data pose new risks against which additional forms of resilience must be developed [7,

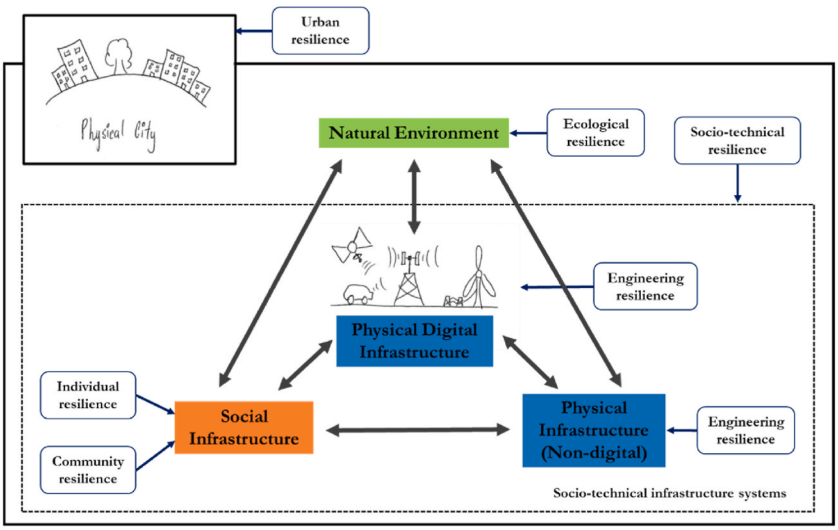


Fig. 3. The resilience of the physical city, understood as a socio-techno-ecological system.

36,65,77,104]. The most common types of threats mentioned in this part of the literature include accidental man-made hazards (e.g., human error), deliberate man-made hazards (e.g., terrorism) and natural hazards [12,31,41,43,52,53,57,60,65]. Discussions therefore focus on making cities and their inhabitants more resilient to shocks associated with such threats.

Here, resilience is defined in broader terms and extends to the social systems of the city, beyond the physical (built and natural environment). Cities are in some cases interpreted as socio-techno-ecological systems in relation to conceptualising urban resilience and sustainability [40,117]. Fig. 3 was developed by the authors of this paper to summarise the interrelations and links between different elements of the 'physical city' (i.e., social infrastructure, physical infrastructure, digital physical infrastructure, and the natural environment), and the associated concepts of resilience found in the papers reviewed. In smart cities, the physical infrastructure includes not only the traditional (non-digital) physical infrastructure but also the new smart digital infrastructure (e.g., IoT systems, smart grids). As Fig. 3 shows, urban resilience emerges as the outcome of the resilience of the different elements and their complex interactions. This is because each element affects the resilience of the other elements due to bi-directional links and feedback loops among them.

A wide range of definitions were found that describe the resilience of the physical city, i.e., urban resilience. Some articles cite definitions coined by recognised organisations such as the United Nations Office for Disaster Risk Reduction (UNDDR) or the Rockefeller Foundation through its initiative 100 Resilient Cities [4,5,12,43,49]. Some of the surveyed articles however develop their own definitions which may focus on specific aspects of resilience, specific hazards or understandings of the interrelations between resilience and smartness.

Garnett and Adams [42]:2) offer a climate change-focused definition of resilience which is seen "*as the ability of a system, which is the urban environment in this case, to cope with stress or disturbance caused by changes in climate*". Moraci et al. [52] link resilience, climate change and smartness in their definition:

> "*the resilient city is an achievement of contemporary planning, which uses smart tools on cities and urban settlements to administrate and manage urban transformations to cope with climate change and the mitigation of environmental hazards. Resilience is a concept included in the meaning of the smart city and is contemplated in the paradigm of smart planning*". [52]:1).

Other authors offer more comprehensive definitions of urban resilience. Timashev [60]:2) contends that

> "*the essence and components of urban resilience consist of working to: 1) prevent any potential threat; 2) withstand any impact caused; 3) react to the crises derived from the impact; 4) recover the city's functionalities; 5) learn from the experience. […] The four main components of urban resilience are: industrial disaster and climate resilience, economic resilience, social resilience and urban resilience. All this is achieved when the city becomes smart*".

Another example of a comprehensive definition is provided by Furno et al. [41]:234):

> "*Resilience describes the ability of a given system to provide fundamental services to people without discontinuity, even in the presence of adverse or catastrophic events. As a consequence, it will be a key property for achieving smartness in cities of the near future. Resilience concerns several infrastructures used for transporting goods or people: energy, water, information and road networks are a few examples. An unforeseen event that originates a breakage in one of these infrastructures may cause incalculable damages with serious socio-economic consequences.*"

The various definitions found in this part of the literature, although emphasising different aspects of urban resilience, converge in agreeing that it involves the capacity of the urban socio-techno-ecological system to absorb, adapt, survive, recover and learn from shocks (see also [40]. Most of the articles surveyed establish a strong link between resilience and smartness. Some contend that a truly smart city must be resilient, others that resilience can only be achieved when a city is smart – giving more emphasis either to 'resilience' or 'smartness'. Some, however, highlight that the implementation of new smart digital technologies may in fact hinder the resilience of the physical city in particular ways (for an example see Ref. [29].

4.2. Linking the concepts of resilience and smartness

Ismagilova et al. [118] argues that smartness in smart cities often refers to the adequate application of various ICT solutions to

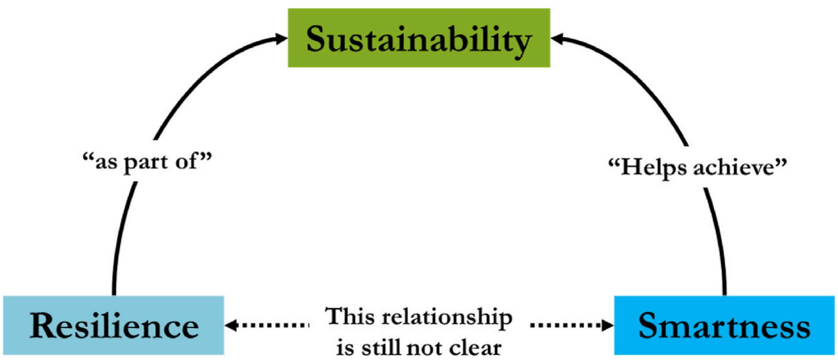


Fig. 4. The Resilience-Smartness-Sustainability triangle.

achieve better performance. However, similar to the concept of resilience, an absolute definition of smartness has not yet been commonly agreed. The literature most often links urban resilience and smartness through the more holistic concept of sustainability, resulting in a 'Resilience-Smartness-Sustainability triangle' (see Fig. 4). 'Resilience' has been recognised as a key aspect of sustainability [39] with resilience goals being included in the United Nations Sustainable Development Goals [7,10]. In turn, smart city visions often emphasise the role of smart city technologies in more efficient, effective and therefore more sustainable urban planning, management and service delivery. In other words, resilience is seen *as part of* urban sustainability, while smartness is a toolbox to *help to achieve* sustainability, as shown on Fig. 4.

However, it must also be noted that the relationship between smartness and resilience remains contested. Different articles offer different interpretations on the nature and quality of this relationship. Some authors argue that the relationship can be positive, negative or neutral depending on the context. Additionally, the literature surveyed shows that the link seems to be clearer from smartness to resilience, rather than the opposite.

Many of those arguing that the interrelations between resilience and smartness lead to mostly positive outcomes either see smart city development as key to improve urban resilience (e.g. de Falco et al. [15]; Dong et al. [38]; Furno et al. [41]; Grimes et al. [43]; Marsal-Llacuna and Segal [51]; Moraci et al. [52]; Oke et al. [55]; Timashev [60]; Wu and Chen [63], or propose specific data-driven solutions and digital tools to improve the resilience of the city or specific urban systems [26,30–32,56,59,61,65]. However, the arguments put forward by these articles are typically justified through simulations rather than real-world implementation and impact measurement (for exceptions see Sitinjak et al. [59]; Zhu et al. [65]. Consequently, empirical evidence demonstrating the positive impact of smartification on urban resilience is still lacking.

Other proponents of a reinforcing relationship between smartness and resilience contend that improving resilience is one of many aspects of smart city development. Resilience is interpreted as a 'service' that smart cities deliver [34,39,53], and therefore a city can only be considered 'smart' if it demonstrates the characteristics of a resilient city [14,28,33,39,41,46,52,64,65].

Depicting the relationship between resilience and smartness as mostly neutral, certain articles in our review propose combining the smart city and the resilient city concepts in one inclusive city model, i.e. the 'smart and resilient' city [11,12,48,49]. Here the argument is that although the concepts overlap, neither can smartness be considered as a component of resilience, nor the other way around. De Jong et al. [5] takes the neutrality argument one step further and asserts that despite any apparent overlaps, in reality there is no straightforward or direct connection between the two concepts.

Some of the surveyed articles however suggest that the interrelations between smartness and resilience may produce negative outcomes overall [4,7,35–37,62,77,119]. They point out that rather than improving urban resilience, smart digital technologies introduce new vulnerabilities into the urban context. This is described as the vulnerability paradox by Ref. [39]:15) as follows:

> *"As a country's utility services become less prone to failure, the greater the effects of any disruption will be (…). In the course of their technological development, societies begin to react much more sensitively to disruptions, especially when they involve infrastructures based on advanced technologies, since the public is used to having very high safety standards and a high degree of security of supply. This situation in which people have developed a rather deceptive feeling of security as services become increasingly reliable and less prone to failure, although the consequences of any 'incident that happens to occur anyway' are disproportionately greater than before, is referred to as the vulnerability paradox."*

We argue that the articles in this group appear to describe a type of a "law of conservation of risk". They acknowledge that smart technologies may be used to enhance the resilience of urban systems (e.g. early warning systems; see Sitinjak et al. [59]. However, they are also likely to introduce new types of risk (e.g. cybersecurity issues; see Kitchin and Dodge [77] to the functioning of these systems. In other cases, smart technologies may simply transfer risk among stakeholders and systems instead of meaningfully dealing with vulnerabilities. Many authors also argue that smart city technologies, in reality, lack the transformative capacity often attributed to them. Instead, they tend to reinforce the status quo and do not tackle the root causes of social, environmental and economic vulnerabilities [4,7].

In summary, the nature of the relationship between smartness and resilience in the urban context is still contested with a diversity of interpretations emerging to date. The debate on their relationship permeates all three components of our conceptualisation of smart cities (recall Fig. 1) as these two concepts are both generic and pervasive (i.e., partly due to the ubiquitous existence of systemic risks and vulnerability and widely applied digital solutions in smart cities). However, improving our understanding of the role of specific digital technologies in processes of 'resilience-building' may help advance the debate.

4.3. The role of digital technologies in resilience-building processes

As discussed in the previous section, consensus has not – and indeed may never – emerge regarding the overall impact of the smart city agenda on urban resilience, and the implications of resilience requirements for smartification in the urban context. Nevertheless, recent market developments indicate an interest in, and potential role for, smart city digital technologies in resilience-building processes. For example, starting from 2019 the Consumer Electronics Show (CES) held in Las Vegas, Nevada, includes a conference programme and exhibition area dedicated specifically to 'Resilience and resilient technologies' [120,121].

The literature review found that digital technologies can play an enabling role in urban resilience-building processes if implemented appropriately. It is however important to note the following. First, smart digital technologies and tools must be considered as part of integrated solution 'packages' rather than standalone solutions. Second, many of the reviewed articles call for paying greater attention to the processes of embedding digital technology in particular social contexts in evaluating their contribution to resilience-building [1,65,99–103,105–109,111,112,115,122]. For instance, Roberts et al. [112,113] perceive digital technologies as 'disruptions' rather than 'enablers', calling for a better understanding of the potentially disruptive nature of digital technologies for urban and community resilience. They assert that:

> "*Technological change is viewed as something that can contribute to adaptive capacity – a resource to be drawn upon – rather than a disruption or change that resilient communities need to be prepared for, but may better be understood as both.*" [112,113]:381)

Bellini and Nesi [104] assert that resilience-building consists of four main elements which they term anticipate, monitor, respond and learn. They see a role for various digital technologies in capacity-building and increasing the efficiency and effectiveness of resilience-building processes. For example, digital models and simulation tools, based on cloud computing and big data, can help to anticipate potential risks, develop emergency scenarios and test emergency responses (see, for example, Alazawi et al. [26]; Bellini et al. [32] or Ottenburger et al. [56]. Urban monitoring and warning systems can benefit from the implementation of IoT, sensing and 5G technologies. Technologies enabling real-time data collection, processing and decision-making can contribute to more appropriate and efficient emergency responses. In addition, advanced data analysis techniques (e.g., Machine Learning) can be utilised to support learning, both in terms of recalibrating the models and systems used in the anticipation phase and providing improved evidence for policymaking. In fact, 'resilience analytics' emerged as a key focus in the literature on digital technology implementation for resilience-building. Barker et al. [103] describe resilience analytics as "*the data-driven process for* supporting *resilience through the application of descriptive, predictive, and prescriptive modelling*" [103]:65).

Taking a different view, Borie et al. [105,106] categorise approaches to resilience-building in terms of their impact and differentiate between 'conservative' and 'transformative' options. An approach is categorised as conservative if it aims at protecting the existing system and its characteristics through facilitating a bounce-back to its baseline functioning after a shock. As such, system characteristics are not challenged and not considered as potential causes of vulnerability. In contrast, transformative approaches seek to utilise the destabilising effects of shocks to facilitate learning about both the system-internal and external causes of vulnerability to improve resilience. Digital technologies can be deployed to support both conservative and transformative processes, adding a new layer of complexity when evaluating the contribution of digital technologies to resilience building.

The importance of context in understanding the impact of digital technologies has been found to be another key consideration in the literature. Borie et al. [105,106] investigate how similar GIS and mapping technologies are used by different stakeholders in Manila, Cape Town and Nairobi to support different resilience narratives in each city. Ashmore et al. [101] describe two case studies of community-led broadband initiatives in rural communities in the UK and show how the incorporation of broadband contributed to increasing resilience in one case but not in the other. According to Ashmore et al., a community can achieve social resilience when people in those communities exhibit strong levels of agency, have a sense of place, and can effectively and efficiently access different kinds of capital. Both community-led broadband initiatives had highly motivated local leaders acting as digital champions, as well as a strong sense of place. The varying results in terms of success lay in the differences in the technical knowledge and capital within the two communities. The relative lack of technical knowledge in one community led to difficulties with accessing financial capital and ultimately proved detrimental to achieving success – leaving this community behind in terms of broadband access and its potential benefits, and less resilient to technological and economic change [65]. present a study in which they assess the resilience of 187 smart cities in China. Although their statistical results show that smartness has a positive impact on urban resilience, the degree of that impact appears to be higher in cities from the Eastern and Southern region of China. They attribute this finding to regional economic development disparities affecting the performance of different cities in China.

These articles aim to show that the impact of smart city digital technologies in resilience building is largely context dependent. They argue that it is essential to build a better understanding of the nature of resilience-building processes and evaluate the potential contribution of digitalisation to facilitate processes that are deemed appropriate and sufficient to deal with particular threats or shocks.

5. Conclusions

This article aimed to build a better understanding of the interrelations between the concepts of 'resilience' and 'smartness' in the urban context. It presented a critical review of literature at the intersection of smart and resilient cities published between 2015 and 2020. The review focused on identifying and comparing the meanings and interpretations attached to 'resilience' therein, as well as the perceived role of digital technologies in resilience building. Our review confirmed that various definitions of resilience exist in the smart city and smart technologies literature. In order to make sense of multiple definitions, we proposed a simple, yet robust, conceptualisation of the 'smart city' and classified the articles according to which of the components of the smart city was their main focus. We defined these components as the 'data layer', 'digital ('smart') technologies' and the 'physical city'. The main conclusions can be summarised as follows.

Despite the emphasis on big data and data analytics in smart cities, we found that only a relatively small number of articles focus specifically on the resilience of this emerging data layer. Some sources which discuss the resilience of smart/digital technologies also incorporate considerations for the data layer, as the resilience of these technologies is seen as being dependent on the resilience of the data. In either case, when discussing the resilience of the data layer a common approach is to discuss resilience in relation to dealing with deliberate man-made hazards (e.g., cyber-attacks) and associated requirements in terms of data security. Other concepts found to have been associated with resilience in the context of data in smart cities include privacy and reliability.

Smart city digital technologies are seen as the interface between the physical city and the data layer, making them vulnerable to threats from both. Therefore, the spectrum of threats considered in this part of the literature ranges from deliberate man-made hazards (e.g., cyber-attacks and terrorism) to natural hazards. Definitions of resilience of digital technologies follow either an engineering resilience or an ecological resilience approach (cf. [96], with key consideration given to service provision requirements – i.e., the ability to guarantee the continuity in the provision of the services provided by smart city digital technologies, for example, smart grids. Consequently, the concept of reliability features strongly in this part of the literature.

The resilience of the physical city is defined in wider terms compared with the former two. One reason for this is the dominant depiction of the city as a complex 'system-of-systems' made up of social and physical infrastructures and the natural environment. The existence (or potential) of complex interactions among these systems means that their different vulnerabilities are interlinked, potentially causing cascading failures across the wider 'system-of-systems'. Consequently, improving the resilience of the physical city entails improving the resilience of all its different subsystems. Untangling the conceptual relationship between smartness and resilience is particularly relevant in this part of the literature, with some authors proposing a strong link between the two concepts while others assert that smartification weakens resilience by introducing new types of vulnerabilities into the already complex system-of-systems arrangements.

We proposed the 'Resilience-Smartness-Sustainability triangle' model which incorporates three dominant concepts in contemporary urban planning and management. The triangle depicts how resilience is most often considered as an element of sustainability, while smartness is perceived as a means to achieve sustainability. This indicates that, on the conceptual level, if smartness contributes to improving sustainability it also may have the potential to help to increase resilience – which is part of sustainability. However, this relationship is far from straightforward. Some of the surveyed papers critique the alleged benefits of smartification for resilience, arguing that the adverse effects of new vulnerabilities introduced by smart city digital technologies cancel any possible benefits. Based on these diverging perspectives, we argue that to investigate the interrelations between resilience and smartness, it is necessary to better understand the specific role of various digital technologies in resilience-building processes.

This is particularly important because the emerging market for digital technologies for resilience-building is ripe with optimistic claims about overly positive outcomes. This optimism is founded on ideas such as 'technological determinism' [113] and 'ecological modernisation' [98]. Here, sustainability is to be achieved through development and progress in terms of technological advancement. This perspective is widespread in the reviewed literature, with the role of digital technologies most often seen as enabling resilience-building processes. However, we argue, the impact of digital technologies on resilience-building processes is likely to depend on *how* these technologies are used and what the *intention* and *expectations* are in relation to their use.

Constructing useful frameworks for understanding resilience-building processes is thus crucial. An example of such a framework which differentiates between conservative and transformational processes (Borie et al. [105,106] was presented earlier in this paper. Learning about the nature of different resilience-building processes can help cities and communities identify and deal with the root causes of vulnerability in a particular context – which in turn should inform the appropriate use of digital technologies to facilitate these processes. Similarly, contextual knowledge held within communities is important in determining which type of resilience-building processes (e.g., conservative or transformational) may be needed in a particular city to deal with specific local vulnerabilities and achieve better resilience. Furthermore, more research is necessary on possible disruptions to cities and communities caused by various smart city digital technologies – especially empirical research that evaluates the results of real-world applications of digital technologies for resilience. This may require some time as many of these technologies are still at prototype stage or have not been implemented for sufficient time in real-world applications to be able to evaluate them.

At this point it must be acknowledged that this lack of real-world applications may partially exist due to focussing our review on academic literature. Future reviews might benefit from contrasting our findings with those arising from a survey of various grey literatures, e.g., consultancy reports, municipal publications and policy documents, to interrogate how the concepts of smartness and resilience are interpreted outside academic research.

Our review highlighted that the debate on the interrelations between smartness and resilience remains open. While this article did not provide a definitive conclusion to this debate, taking stock of the existing literature allowed us to identify useful framings and trends of convergence and divergence, as well as avenues for future research. There is a need for further interdisciplinary research – which extends to the physical, social and environmental systems of cities – to better understand the contribution of specific smart city digital technologies to resilience-building processes in order to increase the understanding of the relationship between smartness and resilience. This conceptual obscurity has wide-reaching implications in urban policy and interventions that seek to improve resilience in a city. It leads to difficulties with scoping problems, setting goals and identifying targets and roles for technologies – with success factors remaining dependent on the views and interpretations of powerful institutions and stakeholders (multinational tech corporations being one example), potentially further marginalising the interests of the less powerful.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research is supported by the Ove Arup Foundation (Digital Cities for Change) (RG89525) and the main part was conducted at the Centre for Smart Infrastructure and Construction (CSIC) at the University of Cambridge.

References

[1] Luke Hespanhol, More than smart, beyond resilient: networking communities for antifragile cities, in: ACM International Conference Proceeding Series Part F1285, 2017, pp. 105–114.
[2] Ayyoob Sharifi, A critical review of selected smart city assessment tools and indicator sets, J. Clean. Prod. 233 (2019) 1269–1283.
[3] Tan Yigitcanlar, Md Kamruzzaman, Marcus Foth, Jamile Sabatini-Marques, Eduardo da Costa, Giuseppe Ioppolo, Can cities become smart without being sustainable? A systematic review of the literature, Sustain. Cities Soc. 45 (November 2018) (2019) 348–365.

[4] Tali Hatuka, Issachar Rosen-Zvi, Michael Birnhack, Eran Toch, Hadas Zur, The political premises of contemporary urban concepts: the global city, the sustainable city, the resilient city, the creative city, and the smart city, Plann. Theor. Pract. 19 (2) (2018) 160–179.
[5] De Jong, Simon Joss Martin, Daan Schraven, Changjie Zhan, Margot Weijnen, Sustainable-smart-resilient-low carbon-eco-knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization, J. Clean. Prod. 109 (2015) 25–38.
[6] Paul D. Mullins, The ubiquitous-eco-city of songdo: an urban systems perspective on South Korea's green city approach, Urban Planning 2 (2) (2017) 4–12.
[7] Maria Kaika, 'Don't call me resilient again!': the new urban agenda as immunology … or … what happens when communities refuse to Be vaccinated with 'smart cities' and indicators, Environ. Urbanization 29 (1) (2017) 89–102.
[8] Lukas Marek, Malcolm Campbell, Lily Bui, Shaking for innovation: the (Re)building of a (smart) city in a post disaster environment, Cities 63 (2017) 41–50.
[9] S. Thomas Ng, Frank J. Xu, Yifan Yang, Mengxue Lu, A master data management solution to unlock the value of big infrastructure data for smart, sustainable and resilient city planning, Procedia Eng. 196 (June) (2017) 939–947.
[10] Zaheer Allam, Peter Newman, Redefining the smart city: culture, metabolism and governance, Smart Cities 1 (1) (2018) 4–25.
[11] Y. Arafah, H. Winarso, D.S.A. Suroso, Towards smart and resilient city: a conceptual model, IOP Conf. Ser. Earth Environ. Sci. 158 (1) (2018).
[12] R. Papa, A. Galderisi, M.C. Vigo Majello, E. Saretta, Smart and resilient cities. A systemic approach for developing, TeMA J. Land Use, Mobil. Environ. 1(Cities, Energy Clim. Change (1) (2015) 1–49.
[13] Bhagya Nathali Silva, Murad Khan, Kijun Han, Towards sustainable smart cities: a review of trends, architectures, components, and open challenges in smart cities, Sustain. Cities Soc. 38 (February) (2018) 697–713.
[14] Y. Arafah, H. Winarso, Redefining smart city concept with resilience approach, IOP Conf. Ser. Earth Environ. Sci. 70 (1) (2017).
[15] Stefano de Falco, Margarita Angelidou, Jean Paul D. Addie, From the 'smart city' to the 'smart metropolis'? Building resilience in the urban periphery, Eur. Urban Reg. Stud. 26 (2) (2019) 205–223.
[16] Royce Francis, Behailu Bekera, A metric and frameworks for resilience analysis of engineered and infrastructure systems, Reliab. Eng. Syst. Saf. 121 (2014) 90–103.
[17] Marcin Baron, Do we need smart cities for resilience, J. Econ. Manag. 10 (2012) 32–46.
[18] Yosef Jabareen, Building a conceptual framework: philosophy, definitions, and procedure, Int. J. Qual. Methods 8 (4) (2009) 49–62.
[19] Tianhu Deng, Keren Zhang, Zuo-Jun Max Shen, A systematic review of a digital twin city: A new pattern of urban governance toward smart cities, J. Manag. Sci. Eng. 6 (2) (2021) 125–134.
[20] Timea Nochta, Li Wan, Jennifer Mary Schooling, Ajith Kumar Parlikad, A socio-technical perspective on urban analytics: the case of city-scale digital twins, J. Urban Technol. 28 (1–2) (2021) 263–287.
[21] Guy Paré, Marie Claude Trudel, Mirou Jaana, Spyros Kitsiou, Synthesizing information systems knowledge: a typology of literature reviews, Inf. Manag. 52 (2) (2015) 183–199.
[22] Maria J. Grant, Andrew Booth, A typology of reviews: an analysis of 14 review types and associated methodologies, Health Inf. Libr. J. 26 (2) (2009) 91–108.
[23] Jill Jesson, Fiona Lacey, How to do (or not to do) a critical literature review, Pharm. Educ. 6 (2) (2006) 139–148.
[24] Claes Wohlin, Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering, ACM International Conference Proceeding Series, 2014.
[25] Henrik Ernstson, Sander E. Va Der Leeuw, Charles L. Redman, Douglas J. Meffert, George Davis, Christine Alfsen, Thomas Elmqvist, Urban transitions: on urban resilience and human-dominated ecosystems, Ambio 39 (8) (2010) 531–545.
[26] Zubaida Alazawi, Alani Omar, Mohmmad B. Abdljabar, Saleh Altowaijri, Rashid Mehmood, A smart disaster management system for future cities, in: WiMobCity 2014 - Proceedings of the 2014 ACM International Workshop on Wireless and Mobile Technologies for Smart Cities, Co-located with MobiHoc 2014, 2014, pp. 1–10.
[27] Leonidas G. Anthopoulos, Christopher G. Reddick, Understanding electronic government research and smart city: a framework and empirical evidence, Inf. Polity 21 (1) (2016) 99–117.
[28] Leonidas Anthopoulos, Marijn Janssen, Vishanth Weerakkody, A unified smart city model (USCM) for smart city conceptualization and benchmarking, E-Plan. Collab. Concepts, Methodol. Tools Appl. 1–3 (1) (2018) 523–540.
[29] Alexandru Bănică, Mihail Eva, Ema Corodescu-Roșca, Bogdan Constantin Ibănescu, Ana Maria Opria, Gabriela Carmen Pascariu, Towards smart(Er) resilient cities. Evidences from Romanian urban areas, Geografie-Sbornik CGS 125 (4) (2020) 397–422.
[30] Omar Bashir, Reducing disaster risks in Indian smart cities: a five-stage resilience maturity model (RMM) approach, Lect. Notes Civ. Eng. 58 (2020) 411–422.
[31] Lars Baumgärtner, Höchst Jonas, Patrick Lampe, Ragnar Mogk, Artur Sterz, Weisenburger Pascal, Mira Mezini, Bernd Freisleben, Smart Street Lights and Mobile Citizen Apps for Resilient Communication in a Digital City, 2019.
[32] Emanuele Bellini, Paolo Nesi, Gianni Pantaleo, Alessandro Venturi, Functional resonance analysis method based-decision support tool for urban transport system resilience management, in: IEEE 2nd International Smart Cities Conference: Improving the Citizens Quality of Life, ISC2 2016 - Proceedings, 2016, pp. 1–7.
[33] Martin Burns, Edward Griffor, Marcello Balduccini, Claire Vishik, Michael Huth, David Wollman, Reasoning about smart city, in: Proceedings - 2018 IEEE International Conference on Smart Computing, SMARTCOMP 2018, 2018, pp. 381–386.
[34] Marianna Cavada, Dexter V.L. Hunt, Chris D.F. Rogers, Do smart cities realise their potential for lower carbon dioxide emissions? Proc. Inst. Civ. Eng.: Eng. Sustain. 169 (6) (2016) 243–252.
[35] Johan Colding, Stephan Barthel, An urban ecology critique on the 'smart city' model, J. Clean. Prod. 164 (2017) 95–101.
[36] Johan Colding, Magnus Colding, Stephan Barthel, The smart city model: A new panacea for urban sustainability or unmanageable complexity? Environ. Plan. B Urban Anal. City Sci. 47 (1) (2020) 179–187.
[37] Brian Deal, Haozhi Pan, Varkki Pallathucheril, Gale Fulton, Urban resilience and planning support systems: the need for sentience, J. Urban Technol. 24 (1) (2017) 29–45.
[38] Xiaojun Dong, Tao Shi, Wei Zhang, Qian Zhou, Temporal and spatial differences in the resilience of smart cities and their influencing factors: evidence from non-provincial cities in China, Sustainability 12 (4) (2020).
[39] Chirine Etezadzadeh, Smart City – Future City? Springer Fachmedien Wiesbaden, Wiesbaden, 2016.
[40] Xinghua Feng, Chunliang Xiu, Limin Bai, Yexi Zhong, Wei Ye, Comprehensive Evaluation of Urban Resilience Based on the Perspective of Landscape Pattern: A Case Study of Shenyang City, 2020. Cities 104.
[41] Angelo Furno, Nour Eddin El Faouzi, Rajesh Sharma, Valerio Cammarota, Eugenio Zimeo, A graph-based framework for real-time vulnerability assessment of road networks, in: Proceedings - 2018 IEEE International Conference on Smart Computing, SMARTCOMP 2018, 2018, pp. 234–241.
[42] Ryan Garnett, Matthew D. Adams, LiDAR-A technology to assist with smart cities and climate change resilience: a case study in an urban metropolis, ISPRS Int. J. Geo-Inf. 7 (5) (2018).
[43] Clara Grimes, Mihoko Sakurai, Vasileios Latinos, A. Tim, Majchrzak, Co-creating communication approaches for resilient cities in europe: the case of the EU project smart mature resilience, in: Proceedings of the International ISCRAM Conference 2017-May(May), 2017, pp. 353–362.
[44] M.R. Janitra, Implementation of smart city for building disaster resilience in west Java province, in: IOP Conference Series: Earth and Environmental Science, vol. 592, IOP Publishing Ltd, 2020.
[45] Vit Janos, Tomas Horak, Miroslav Svitek, Smart public rail transit system for el paso, in: 2019 Smart City Symposium Prague (SCSP), 2019, pp. 1–5.
[46] Fahmida Khandokar, Antonio Bucchiarone, Monjur Mourshed, SMART: a process-oriented methodology for resilient smart cities, in: IEEE 2nd International Smart Cities Conference: Improving the Citizens Quality of Life, ISC2 2016 - Proceedings, 2016, pp. 1–6.
[47] N. Komninos, C. Kakderi, A. Panori, P. Tsarchopoulos, Smart city planning from an evolutionary perspective, J. Urban Technol. 26 (2) (2019) 3–20.
[48] Matthew Liotine, Arkalgud Ramaprasad, Thant Syn, Managing a smart city's resilience to ebola: an ontological framework, in: Proceedings of the Annual Hawaii International Conference on System Sciences 2016-March, 2016, pp. 2935–2943.

[49] Nisrine Makhoul, From sustainable to resilient and smart cities, in: IABSE Conference, Geneva 2015: Structural Engineering: Providing Solutions to Global Challenges - Report, 2015, pp. 1901–1906.
[50] Marsal-Llacuna, Maria Lluïsa, Mark Evan Segal, The intelligenter method (I) for making 'smarter' city projects and plans, Cities 55 (2016) 127–138.
[51] Marsal-Llacuna, Maria-Luisa, Mark Evan Segal, The intelligenter method (II) for 'smarter' urban policy-making and regulation drafting, Cities 61 (2017) 83–95.
[52] Francesca Moraci, Maurizio Francesco Errigo, Celestina Fazia, Gianluca Burgio, Sante Foresta, Making less vulnerable cities: resilience as a new paradigm of smart planning, Sustainability 10 (3) (2018) 1–18.
[53] Karam Mustapha, Hamid Mcheick, Sehl Mellouli, Smart cities and resilience plans: a multi-agent based simulation for extreme event rescuing, in: Smarter as the New Urban Agenda: A Comprehensive View of the 21st Century City, Public Administration and Information Technology, 2016, pp. 149–170.
[54] Sophie A. Nitoslawski, Nadine J. Galle, Cecil Konijnendijk van den Bosc, James W.N. Steenberg, Smarter ecosystems for smarter cities? A review of trends, technologies, and turning points for smart urban forestry, Sustain. Cities Soc. 51 (July) (2019) 101770.
[55] Ayodeji Emmanuel Oke, Douglas O. Aghimien, Opeoluwa I. Akinradewo, Clinton O. Aigbavboa, Improving resilience of cities through smart city drivers, Construct. Econ. Build. 20 (2) (2020) 45–64.
[56] Sadeeb Ottenburger, Miimu Airaksinen, Isabel Pinto-Seppa, Wolfgang Raskob, Enhancing urban resilience via a real-time decision support system for smart cities, in: 2017 International Conference on Engineering, Technology and Innovation: Engineering, Technology and Innovation Management beyond 2020: New Challenges, New Approaches, ICE/ITMC 2017 - Proceedings 2018-Janua, 2018, pp. 836–844.
[57] Ulrike Passe, Nadia Anderson, Kris De Brabanter, Michael C. Dorneich, Caroline Krejci, Methodologies for studying human-microclimate interactions for resilient , smart city decision- making, Ind. Manufact. Syst. Eng. Conf. Proc. Posters 21 (3) (2016) 1735–1742.
[58] Tomáš Peltan, Daniel Franke, Jakub Vorel, Karel Maier, Model for evaluation of transport energy needs of alternative development scenarios on regional scale, in: 2017 Smart Cities Symposium Prague, SCSP 2017 - IEEE Proceedings, 2017.
[59] Efraim Sitinjak, Bevita Meidityawati, Ronny Ichwan, Niken Onggosandojo, Parinah Aryani, Enhancing urban resilience through technology and social media: case study of urban Jakarta, Procedia Eng. 212 (2017) (2018) 222–229.
[60] S.A. Timashev, Resilient urban infrastructures - basics of smart sustainable cities, IOP Conf. Ser. Mater. Sci. Eng. 262 (1) (2017).
[61] Kanaris Tsinganos, Evangelos Gerasopoulos, Iphigenia Keramitsoglou, Nicola Pirrone, ERA-PLANET, a European network for observing our changing planet, Sustainability 9 (6) (2017) 1040.
[62] Jenni Viitanen, Richard Kingston, Smart cities and green growth: outsourcing democratic and environmental resilience to the global technology sector, Environ. Plann. 46 (4) (2014) 803–819.
[63] Yenchun Jim Wu, Jeng-Chung Chen, A structured method for smart city project selection, Int. J. Inf. Manag. (July) (2019) 1–9.
[64] Masaru Yarime, Facilitating data-intensive approaches to innovation for sustainability: opportunities and challenges in building smart cities, Sustain. Sci. 12 (6) (2017) 881–885.
[65] Shiyao Zhu, Dezhi Li, Haibo Feng, Is smart city resilient? Evidence from China, Sustain. Cities Soc. 50 (December 2018) (2019) 101636.
[66] David Perez Abreu, Karima Velasquez, Marilia Curado, Edmundo Monteiro, A resilient internet of Things architecture for smart cities, Annales Des Telecommunications/Annals of Telecommunications 72 (1–2) (2017) 19–30.
[67] David Perez Abreu, Karima Velasquez, Alexandre Miguel Pinto, Marilia Curado, Edmundo Monteiro, Describing the internet of Things with an ontology: the SusCity project case study, in: Proceedings of the 2017 20th Conference on Innovations in Clouds, Internet and Networks, ICIN 2017, 2017, pp. 294–299.
[68] Ruba A. Amarin, Issa Batarseh, Steve Rhoades, Efficient energy solutions: enabling smart city deployment, FTC 2016 - Proc. Fut. Technol. Conf. (December) (2017) 791–795.
[69] Anuradha M. Annaswamy, Ahmad R. Malekpour, Stefanos Baros, Emerging research topics in control for smart infrastructures, Annu. Rev. Control 42 (2016) 259–270.
[70] Gerhard Brown, Neco Ventura, Mwangama Joyce, A software defined approach for improving resilience in smart distribution grids, in: 2020 International SAUPEC/RobMech/PRASA Conference, SAUPEC/RobMech/PRASA 2020, Institute of Electrical and Electronics Engineers Inc, 2020.
[71] Thidapat Chantem, Nan Guan, Duo Liu, Sustainable embedded software and systems, Sustain. Comput. Inf. Syst. 22 (2019) 152–154.
[72] Rajat Chaudhary, Anish Jindal, Gagangeet Singh Aujla, Shubhani Aggarwal, Neeraj Kumar, Kim Kwang Raymond Choo, BEST: blockchain-based secure energy trading in SDN-enabled intelligent transportation system, Comput. Secur. 85 (2019) 288–299.
[73] Andrea Chiappetta, Gianni Cuozzo, Critical infrastructure protection: beyond the hybrid port and airport firmware security cybersecurity applications on transport, in: 5th IEEE International Conference on Models and Technologies for Intelligent Transportation Systems, MT-ITS 2017 - Proceedings, 2017, pp. 206–211.
[74] Stanislav Chren, Bruno Rossi, Barbora Bühnova, Tomáš Pitner, Reliability data for smart grids: where the real data can Be found, in: 2018 Smart Cities Symposium Prague, SCSP 2018, 2018, pp. 1–6.
[75] Antonio Gomez-Exposito, Angel Arcos-Vargas, M. Jose, Maza-Ortega, A. Jose, Rosendo-Macias, Gabriel Alvarez-Cordero, Susana Carillo-Aparicio, Juan Gonzalez-Lara, Daniel Morales-Wagner, Tomas Gonzalez-Garcia, City-friendly smart network technologies and infrastructures: the Spanish experience, Proc. IEEE 106 (4) (2018) 626–660.
[76] Oliver Jung, Sandford Bessler, Andrea Ceccarelli, Tommaso Zoppi, Alexandr Vasenev, Lorena Montoya, Tony Clarke, Keith Chappell, Towards a collaborative framework to improve urban grid resilience, in: 2016 IEEE International Energy Conference, ENERGYCON 2016, 2016, pp. 1–6.
[77] Rob Kitchin, Dodge Martin, The (In)Security of smart cities: vulnerabilities, risks, mitigation, and prevention, J. Urban Technol. 26 (2) (2019) 47–65.
[78] Krzysztof Lewandowski, Protection of the smart city against CME, Transport. Res. Procedia 16 (March) (2016) 298–312.
[79] Zhiyi Li, Mohammad Shahidehpour, Farrokh Aminifar, Alabdulwahab Ahmed, Yusuf Al-Turki, Networked microgrids for enhancing the power system resilience, Proc. IEEE 105 (7) (2017) 1289–1310.
[80] Thaha Muhammed, Rashid Mehmood, Aiiad Albeshri, Enabling reliable and resilient IoT based smart city applications, in: R. Mehmood, B. Bhaduri, I. Katib, I. Chlamtac (Eds.), Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol. 224, Springer International Publishing, Cham, 2018, pp. 169–184.
[81] K. Øien, L. Bodsberg, A. Jovanović, Resilience assessment of smart critical infrastructures based on indicators, in: Safety and Reliability - Safe Societies in a Changing World - Proceedings of the 28th International European Safety and Reliability Conference, ESREL 2018 (Hsac 2006), 2018, pp. 1269–1278.
[82] Christos Panagiotou, Christos Antonopoulos, Stavros Koubias, A comprehensive evaluation of cache utilization characteristics in large scale WSN considering network driven cache replacement techniques, MATEC Web Conf. 188 (2018).
[83] Javier Poncela, Panagiotis Vlacheas, Raffaele Giaffreda, Suparna De, Massimo Vecchio, Septimiu Nechifor, Raquel Barco, Mari Carmen Aguayo-Torres, Stavroulaki Vera, Klaus Moessner, Panagiotis Demestichas, Smart cities via data aggregation, Wireless Pers. Commun. 76 (2) (2014) 149–168.
[84] Arman Roohi, Ronald F. Demara, Longfei Wang, Selcuk Kose, Secure intermittent-robust computation for energy harvesting device security and outage resilience, in: 2017 IEEE SmartWorld Ubiquitous Intelligence and Computing, Advanced and Trusted Computed, Scalable Computing and Communications, Cloud and Big Data Computing, Internet of People and Smart City Innovation, 2018, pp. 1–5. SmartWorld/SCALCOM/UIC/ATC/CBDCom/IOP/SCI 2017 - (c).
[85] Mohammad Shahidehpour, Microgrids for enhancing the economics, reliability, and resilience of smart cities - an IIT experience, in: Smart Grid Conference 2014, 2014. *SGC 2014* 1.
[86] James P.G. Sterbenz, Smart city and IoT resilience, survivability, and disruption tolerance: challenges, modelling, and a survey of research opportunities, in: Proceedings of 2017 9th International Workshop on Resilient Networks Design and Modeling, RNDM 2017, 2017, pp. 1–6.
[87] Sen Tan, Yanpeng Wu, Peilin Xie, Josep M. Guerrero, Juan C. Vasquez, Abdullah Abusorrah, New challenges in the design of microgrid systems: communication networks, cyberattacks, and resilience, IEEE Electrification Mag. 8 (4) (2020) 98–106.
[88] Rui Teng, Huan Bang Li, Bing Zhang, Ryu Miura, Differentiation presentation for sustaining internet access in a disaster-resilient homogeneous wireless infrastructure, IEEE Access 4 (2016) 514–528.

[89] Takahiro Toda, Yosuke Tanigawa, Hideki Tode, Autonomous and distributed construction of locality aware skip graph, in: 2017 14th IEEE Annual Consumer Communications and Networking Conference, CCNC 2017, 2017, pp. 33–36.
[90] Jó Ueyama, Bruno S. Faiçal, Leandro Y. Mano, Guilherme Bayer, Gustavo Pessin, H. Pedro, Gomes, Enhancing reliability in wireless sensor networks for adaptive river monitoring systems: reflections on their long-term deployment in Brazil, Comput. Environ. Urban Syst. 65 (2017) 41–52.
[91] Jiankang Wang, Toward resilience of the electric grid, in: Smart Cities, John Wiley & Sons, Inc, Hoboken, NJ, USA, 2017, pp. 535–574.
[92] Adeel Anjum, Tahir Ahmed, Abid Khan, Naveed Ahmad, Mansoor Ahmad, Muhammad Asif, Alavalapati Goutham Reddy, Tanzila Saba, Nayma Farooq, Privacy preserving data by conceptualizing smart cities using MIDR-angelization, Sustain. Cities Soc. 40 (January) (2018) 326–334.
[93] H.A. Boyes, R. Isbell, P. Norris, T. Watson, Enabling intelligent cities through cyber security of building information and building systems, IET Seminar Digest 2014 (15564) (2014) 1–6.
[94] Weichao Gao, Wei Yu, Liang Fan, William G. Hatcher, Chao Lu, Privacy-Preserving Auction for Big Data Trading Using Homomorphic Encryption, IEEE Transactions on Network Science and Engineering, 2018, p. 1.
[95] Anoova Guthikonda, Ehab Al-Shaer, Abdullah Farooq, M. Yasin Akhtar Raja, Bio-inspired innovations in cyber security, in: 2017 14th International Conference on Smart Cities: Improving Quality of Life Using ICT and IoT, HONET-ICT 2017 2017-Janua, 2017, pp. 105–109.
[96] Janine S. Hiller, Jordan M. Blanke, Smart cities, big data, and the resilience of privacy, Hastings Law J. 68 (2) (2017) 309–356.
[97] Olivera Kotevska, A. Gilad Kusne, Daniel V. Samarov, Lbath Ahmed, Abdella Battou, Dynamic network model for smart city data-loss resilience case study: city-to-city network for crime analytics, IEEE Access 5 (2017) 20524–20535.
[98] Ian Bailey, Geoff A. Wilson, Theorising transitional pathways in response to climate change: technocentrism, ecocentrism, and the carbon economy, Environ. Plann. 41 (10) (2009) 2324–2341.
[99] Dave Yates, Paquette Scott, Emergency knowledge management and social media technologies: a case study of the 2010 Haitian earthquake, Int. J. Inf. Manag. 31 (1) (2011) 6–13.
[100] Andrew Garbett, Rob Comber, Edward Jenkins, Patrick Olivier, App movement: a platform for community commissioning of mobile applications, Conf. Human Fact. Comput. Syst.- Proc. (2016) 26–37.
[101] Fiona H. Ashmore, John H. Farrington, Sarah Skerratt, Community-led broadband in rural digital infrastructure development: implications for resilience, J. Rural Stud. 54 (2017) 408–425.
[102] Neha Bansal, Mahua Mukherjee, Ajay Gairola, in: F. Seta, J. Sen, A. Biswas, A. Khare (Eds.), From Poverty, Inequality to Smart City, Springer Singapore, Singapore, 2017.
[103] Kash Barker, James H. Lambert, Christopher W. Zobel, Andrea H. Tapia, Jose E. Ramirez-Marquez, Laura Albert, Charles D. Nicholson, Cornelia Caragea, Defining resilience analytics for interdependent cyber-physical-social networks, Sustain. Resilient Infrastruct. 2 (2) (2017) 59–67.
[104] Emanuele Bellini, Paolo Nesi, Exploiting smart technologies to build smart resilient cities, in: Routledge Handbook of Sustainable and Resilient Infrastructure, Routledge, 2018, pp. 685–705.
[105] Maud Borie, Mark Pelling, Gina Ziervogel, Hyams Keith, Mapping narratives of urban resilience in the global south, Global Environ. Change 54 (2019) 203–213.
[106] Maud Borie, Mark Pelling, Gina Ziervogel, Hyams Keith, Mapping narratives of urban resilience in the global south, Global Environ. Change 54 (December 2018) (2019) 203–213.
[107] Jon Coaffee, Katerina Hadjimatheou, Enhancing Public Security through Use of Social Media: the Good, the Bad and the Ugly, 2019, pp. 1–14.
[108] Mark Duffield, The resilience of the ruins: towards a critique of digital humanitarianism, Resilience 4 (3) (2016) 147–165.
[109] Mareile Kaufmann, Resilience 2.0: social media use and (Self-)Care during the 2011 Norway attacks, Media Cult. Soc. 37 (7) (2015) 972–987.
[110] Glenn Lyons, Getting smart about urban mobility – aligning the paradigms of smart and sustainable, Transport. Res. Pol. Pract. 115 (2018) 4–14.
[111] Elisabeth Roberts, John Farrington, Sarah Skerratt, Evaluating new digital technologies through a framework of resilience, Scot. Geogr. J. 131 (3–4) (2015) 253–264.
[112] Elisabeth Roberts, David Beel, Lorna Philip, Leanne Townsend, Rural resilience in a digital society: editorial, J. Rural Stud. 54 (2017) 355–359.
[113] Elisabeth Roberts, Brett Anne Anderson, Sarah Skerratt, John Farrington, A review of the rural-digital policy agenda from a community resilience perspective, J. Rural Stud. 54 (2017) 372–385.
[114] Trebor Scholz, Platform cooperativism vs. the sharing economy, in: Big Data & Civi Engagement, 2017, pp. 47–55.
[115] Yenni Tim, Shan L. Pan, Peter Ractham, Laddawan Kaewkitipong, Digitally enabled disaster response: the emergence of social media as boundary objects in a flooding disaster, Inf. Syst. J. 27 (2) (2017) 197–232.
[116] Vasillis Vlachokyriakos, Clara Crivellaro, A. Christopher, Le Dantec, Eric Gordon, Pete Wright, Patrick Olivier, Digital civics, in: Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '16, ACM Press, New York, New York, USA, 2016, pp. 1096–1099.
[117] Emile J.L. Chappin, Telli van der Lei, Adaptation of interconnected infrastructures to climate change: a socio-technical systems perspective, Util. Pol. 31 (2014) 10–17.
[118] Elvira Ismagilova, Laurie Hughes, Yogesh K. Dwivedi, K. Ravi Raman, Smart cities: advances in research—an information systems perspective, Int. J. Inf. Manag. 47 (2019) 88–100.
[119] Ove Arup & Partners Ltd, National Infrastructure Commission Infrastructure and Digital Systems Resilience Final Report - November 2017, 2017 (November).
[120] Business Wire, Inc., Resilience to Be New Part of CES 2019, 2020. Retrieved, https://www.businesswire.com/news/home/20180919005205/en/Resilience-New-Part-CES-2019. (Accessed 16 July 2020).
[121] Consumer Technology Association, CES 2019 - Resilience, 2020. Retrieved, https://www.ces.tech/Topics/5G-and-Internet-of-Things-(IoT)/Resilience.aspx. (Accessed 19 March 2020).
[122] Sahil, Sandeep Kumar Sood, Fog-cloud centric IoT-based cyber physical framework for panic oriented disaster evacuation in smart cities, Earth Sci. Inf. (2020) 1–22.
[123] Lemonia Ragia, Antoniou Varvara, Making smart cities resilient to climate change by mitigating natural hazard impacts, ISPRS Int. J. Geo-Inf. 9 (3) (2020) 153.
[124] Carlo Vermiglio, Hiroko Kudo, Zarone Vincenzo, Making a step forward towards urban resilience. The contribution of digital innovation. International symposium: New metropolitan perspectives, Springer, Cham, 2020, pp. 113–123.
[125] Achillopoulou, Dimitra V., Stergios A. Mitoulis, Sotirios A. Argyroudis, and Ying Wang. Monitoring of transport infrastructure exposed to multiple hazards: A roadmap for building resilience. *Sci. Total Environ.* 746 (2020): 141001.