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REVIEW

Exploring urban resilience thinking for its application in urban planning: a review of literature

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Abstract

Environmental and urban problems are rooted in both ecology and urbanism contexts. The main issue in this regard is to plan, design and manage urban settlements where human beings would be able to have the desirable quality of life according to sustainable principles. The increase in social, economic and spatial vulnerabilities in cities, and the excess of degradation factors of natural environment resources show the necessity of considering resilience thinking. This paper aims to apply resilience thinking to urban studies and to identify the required basis for further research on urban resilience through a descriptive analytical review of the theoretical literature. A recent research on urban resilience in urbanization, which is a novel topic in urban resilience studies is addressed in this article. This paper aimed at introducing indices of urban resilience through a particular approach to the relationship between urban form and urban resilience. Given the literature review of urban resilience, our results show that while most research topics rely on environmental dimensions and reduction in natural hazards, such as global warming and climate change, the need for further research on spatial morphology and urban spatial structures is evident. Furthermore, additional research is needed to explore the criteria of urban resilience measurement specifically in the locational-spatial aspect.

Keywords Resilience thinking · Urban resilience · Urban planning · Urban system

Introduction

Cities are an example of complex systems. Having interconnected components, such an alive dynamic system is influenced by various factors that are constantly evolving and changing. The pace of these changes is too fast to fully understand the various factors causing the change, especially in developing cities. This is a reason why cities are such complex subjects and why it is difficult to find simple solutions (Redman 2014). To counterbalance the fact that the world's cities cause crisis and environmental threats to the planet, urban planners and experts are looking for solutions and ways to confront these changes in the realm of cities. An example of such changes is the acceleration of urbanization, which has hit cities all over the world with varying degrees of influence. According to a report by the United Nations in 2014, about two-thirds of the world's population will be urbanized by 2050 (United Nations 2014).

The global environmental crisis has been reported by the World Summit on Sustainable Development in relation to the high speed of urbanization and its effects on social, ecological and urban infrastructure. These effects include the critical climate change on the planet, depletion of non-renewable natural resources and drought (especially in arid and semiarid regions such as Iran). The effects also include elimination of biodiversity in plant and animal species, deforestation, spread of pollution in the seas and oceans, destruction of the ozone layer and the increase in greenhouse gases (Secretariat of the National Committee for Sustainable Development 2003). Studies show that, nowadays, cities account for 75% of energy consumption, 60% of tap water

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consumption, 80% of wood consumption for industrial purposes and 80% of global greenhouse gas emissions (Grimm et al. 2008).

Therefore, one of the most controversial issues nowadays is how to deal with changes in the world's cities, and their role in solving these problems. These concerns stimulate city planners and governments to search for ways to respond to such challenging changes in the cities. Today, well designed or managed urban areas are also confronted with many problems. Significant progress has been made concerning emerging hazards at the global level, so that the dominant view has shifted from pure focus on vulnerability reduction to an increased resilience to disasters. Based on this view, risk reduction programs should seek to create and strengthen the characteristics of resilient societies and focus on the concept of resilience thinking (Rafieian et al. 2011).

Proposed by Holling (1973) and then developed by Walker and Salt (2006), the framework of resilience has been put forward as a fundamental force that works at different levels, due to its emphasis on the relationship between social systems and ecological systems (Folke et al. 2010; Folke 2006). On the other hand, the framework of such thought is to encounter with the transformations which urban systems are faced with (Richard et al. 2003). Therefore, a set of challenges, including inadequate response to the changes and management of hazards and threats to cities, reveal the need for better and more accurate definition of resilience and its application in the urban system to cope with the changes. This paper aims to identify the concept of urban resilience and introduce related research fields along with the review of the theoretical literature of resilience thinking. It also seeks its application in urban planning, because many researchers agree that the identification of the principles of resilience thinking considerably contributes to the emergence of a sustainable urban system (Chapin et al. 2011; Clark 2007; Odum and Odum 2001).

Research materials and methods

The conceptual framework of this study is based on an investigation into the relationship between ecology, urban knowledge and urban resilience thinking. In this study, a classification of the literature is pursued using content analysis. It also aims to provide a better understanding of the resilience of an urban system obtained with the increased use of resiliency thinking, especially in regard to urban studies. Therefore, firstly, this study presents the definitions of concepts and theoretical foundations of resilience thinking to clarify the subject. Then, the literature review associated with the articles and researches is presented, with keywords such as "resilience" and its combination with terms relevant to city, urban planning and urban morphology, such as "urban resilience" and "resilience and urban morphology." The literature review on the history of resilience thinking showed that studies addressing resilience thinking in relation to the city and to the urban system are found under the titles of "resilient cities" and "resilience of urban system." In order to collect information and systematically review the theoretical literature, research was conducted by searching through libraries and scientific databases, especially Scopus, Web of Science and Science Direct. Next, the concepts of urban system, resilience thinking and resilience indices within an urban system were studied and analyzed from the beginning of studies about resilience thinking in urban planning until 2016, and the literature review associated with the title of urban resilience is done. The purpose is to allow for better application of the subject in the future.

Concepts, definition and literature review of resilience thinking

Definitions from the general and the ecological concept to be redefined in urbanism

General Definition of Resilience: Resilience thinking is defined by various terms, based on which conceptual circles have been formed. However, there is a consensus on this conceptual issue. According to the scientifically oft-cited research by Alberti et al., resilience is "the extent to which a system is capable of absorbing risks and reorganizing itself." Based on that, resilience is a combination of "absorbing disturbances and achieving a balance," "self-reorganizing" and "increasing the capacity for learning and adaptation" (Alberti et al. 2003). According to Carpenter et al., similar to the definition given by Alberti et al., "Resonance is the amount of disturbance that a system can absorb and still remain in the same structural, cognitive and identity status. In other words, it refers to the ability of a system to reorganize itself (in contrast to the lack of organization or being organized under external forces) and create and increase its learning and adaptation capacity" (Carpenter et al. 2009). Adger, another thinker in this regard, defined the resilience in accordance with ecology and ecological systems; resilience thinking refers to the capacity of ecological systems to absorb disturbances while maintaining the intrinsic feedbacks, processes and structures (Adger 2003).

In his definition, he emphasized the maintenance of inherent features and structures of the system after the occurrence of changes. Accordingly, Gunderson and Holling also presented a similar definition with emphasis on maintaining the structure of the system; "The severity of the disruption that a system can absorb before the structure swings to a different one through changes of the variables and processes controlling its behavior" (Gunderson and Holling 2002). According to the definitions above, the common point of resilience thinking that should be considered is the ability or capacity to absorb disruption and risk. Additionally, the ability to adapt to change, improve and maintain the inherent features and structures of the system, referring to the resilient character of a system, has to be taken into account (Linkov et al. 2014).

Resilience in Ecology and the Ecological Approach: Resilience is defined as two entirely different implicit meanings in ecology. The first implicit connotation of resilience is based on the classic ecological paradigm, which emphasizes a phase of equilibrium, and is based on the return of a system to its equilibrium after an inconsistency, usually measured in a time unit (Innis 1975). The concept of "classical resilience" is based on the principle of equilibrium and balance that focuses on efficiency, stability and predictability, and it is called "engineering resilience." In contrast to this definition, the second implicit meaning of resilience is "ecological resilience" or "ecosystem resilience" defined as the ability of a system to absorb the change and disturbance without variation of its function and structure or transition to a different phase, according to Holling (1973). This implies that ecosystems often have multiple sustainable phases and emphasizes the principle of permanent changes and unpredictability of the system (Holling 1996). New discussions about resilience are related to ecological resilience rather than engineering resilience. Most of the recent research has addressed Holling's original definition of ecological and ecosystem resilience.

In the field of ecology, engineering resilience (based on the classic ecological paradigm) leads to stability of the system and seeks homogeneity, predictability and inherent sustainability of ecosystems, in contrast to the new paradigm which is based on the hierarchy of diversity. In the new paradigm, the sustainability of ecosystems is heterogeneous and nonlinear with multiple stages, expressing the "alteration of nature" and "order in chaos" (Pickett et al. 2004; Wu and Loucks 1995). A complex system rarely stays within a balance point or stable condition for a long time. Therefore, if the stability of the system is disturbed, there will be two possible scenarios; first, the resilience of the system will allow it to continue its function through some settings in its operation and to remain in a stable state or in the same equilibrium point where it was before being disturbed. Second, the resilience of the system rises and the system is transferred to a different stability state (Gunderson and Holling 2002). In this situation, predictability is very low and opportunities are unknown, resulting in instability of the system. The system's resilience features should be evaluated in a wider perspective that always takes into account the importance of internal dynamics of the system in relation to the external influences around it (Abid 2016; Garcia 2013). A system can continue to operate in a familiar environment and, if resilience capacity increases, it suddenly moves into a different environment. Therefore, the resilience capacity is what maintains the system at the threshold of stability when disturbances attempt to transfer it to another state. In fact, different aspects of engineering and ecological resilience help determine whether a system can return to its previous state or be displaced to a different but steady state. While engineering resilience suggests reconstruction characteristics in which an entity can return to its original form after confrontation with an imbalance, the ecological resilience explains a state of multiple balance points where the system can be adapted to the change through renewal by moving forward with a new form (Abid 2016). Pickett et al. (2004) proposed substitution of ecological resilience for engineering resonance as a robust concept to bridge the gap between ecology and urbanization. From this perspective, resilience includes the capabilities of a system for self-sufficiency and adaptability to changes as well as trends that make resilience more dependent on socio-ecological systems (Holling 1996; Carpenter et al. 2009; Adger et al. 2005; Folke 2006).

Resilience from urbanization perspective: It is very important to understand the concept of resilience of a system (especially not only in ecological systems but also in urban systems including complex socio-ecological, economic relations). Furthermore, it is significant to distinguish the "resilience" and the "equilibrium point," which do not mean the same at all (as mentioned by Holling at the very beginning of his discussion about ecological resilience) (Holling 1973). Urban resilience is not necessarily the ability of a system to go back to the previous state and equilibrium point while the system is experiencing the disruption or shock. The previous state and former equilibrium point may have disappeared or partially vanished for a variety of reasons, and alternative ways probably emerged; so it is necessary to note that all of these scenarios and potential options can change the system's path. According to Adger (2003), all ecological definitions

Table 1 Three conceptual approaches of resilience thinking

Resilience approaches	Descriptions	References
Resilience as recovery	The ability of the system to absorb disturbances and achieve a balance through recovery	Folke (2006)
Resilience as compatibility or adaptation capacity	The capacity to absorb pressures or destructive forces by adaptation to the change	Carpenter et al. (2009) Chelleri et al. (2016)
Resilience as change	The ability of the system to absorb disturbances and adaptively respond to the change through a positive shift toward transformation	Folke et al. (2010)

highlight the degree of destruction that a system can withstand without changing the conditions. In his view, the focus is almost on sustainability and resilience against degradation and the speed of return to equilibrium. The classical ecological definitions seem to believe in the existence of an equilibrium point within the system and regard resilience as the preservation of the system in its existing structural state or as the speed of the system's return to its previous state (before pressures and changes were applied). In classical ecological definitions, the recovery process after an accident is to recover or quickly return to the past characteristics, aiming to maintain the balance. However, in new ecological definitions, which particularly approach the urbanization perspective, resilience thinking has contributed to a long-term recovery process through procedures such as renewal, rehabilitation and reorganization after an accident, absolutely different from the classical ecological point of view. In fact, the (urban) system may seem like the pre-accident or pre-change situation, but the fact is that it is not the same as the previous system, with the same structure and performance. Hence, urban resilience focuses on concepts such as "status change and regime shift" and "attracting change" rather than "stable states" or "equilibrium and stability," so that the dynamics of the urban system are also respected in this view (Folke 2006). Thus, there are two general points in definitions of resilience. Firstly, resilience is considered an ability or flow rather than a result and, secondly, resilience contributes to compatibility rather than stability, so that it provides instability, change and regime shift to a new equilibrium, while stability or inability to change or adapt is conceived as the lack of resilience.

Conceptual approaches of resilience thinking

In resilience thinking, the concept of compatibility and adaptability to changes is important, referring to the ability and capacity of the system to reorganize itself and maintain its fundamental structures. In other words, this approach enfolds the concept of sustainability that is based on long-term survival without a drop in quality of life and on more sustainable use of system resources. In total, three general conceptual approaches to resilience can be identified:

Resilience as recovery it contributes to the system's ability to "return to the past" or return from a change or pressure factor to the primary state, measured as the time taken by a community to recover from the change. A resilient system can return to the previous state rather quickly, while a less resilient system may take more time to recover or may not even recover. In other words, according to Carpenter et al., a resilient system must possess these features:

- Capacity to absorb pressures or destructive forces by employing sustainability and adaptability factors;
- Capacity to manage and maintain basic structures and functions during accidents;
- Capacity to "return to the past"; to recover after an accident (Carpenter et al. 2009).

Resilience as compatibility or adaptation capacity this approach is expanded from ecological studies that define resilience as the ability to return to the previous state. In this approach, resilience is described as the amount of disruption that a system can tolerate or absorb before transferring to another state (Folke 2006). In other words, it refers to the capacity to absorb pressures or destructive forces by adaptation to the change (Carpenter et al. 2009; Chelleri et al. 2016).

Resilience as change this approach is highly related to the system's capacity to respond adaptively to the change, which can be in terms of a positive shift toward sustainable development, instead of a simple return to the previous state. This approach is associated with the concepts of renewal, rehabilitation and self-reorganization. In this approach, a change, disruption or accident provides potential opportunities within the system for new experiences in innovation and development (Folke et al. 2010). In this approach, the features of the system that are less likely to return to the previous state are identified so that they can be transformed by an external change through an adaptive approach. Therefore, this approach highlights the strength, self-organization and change in dimensions through resilience (Table 1).

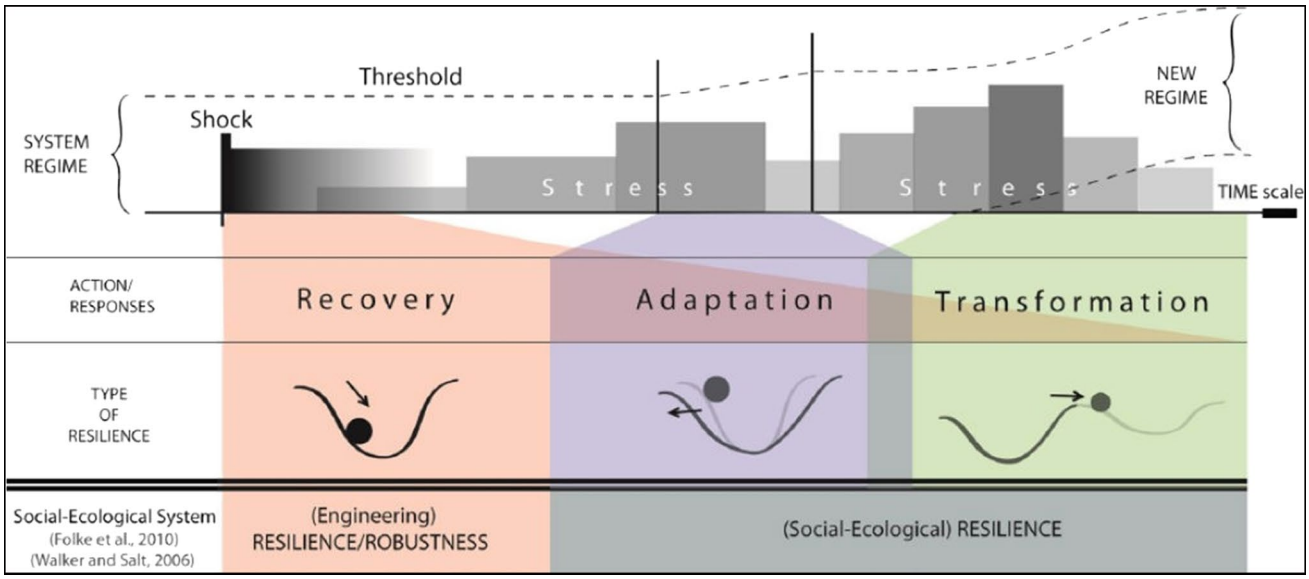

Fig. 1 Three conceptual approaches of resilience thinking in disturbances (Chelleri and Olazabal 2012, p 70)

A common aspect of all these approaches is the ability to withstand, resist and respond positively to pressure or change. The first and second approaches have a definite understanding of resilience as an inherent characteristic of the system that enables it to adapt to the pressure factor or not and, in other words, proves whether a system is resilient. Unlike the first and second approaches, the third approach contemplates the system's capacity for compatibility instead of focusing on the vulnerability of the system (Fig. 1). A resilient society can use the experiences obtained by changes to achieve better performance through this approach, so that it can react in a creative and innovative way to change rather than survival and self-restraint against the pressure factor (Rafieian et al. 2011).

Furthermore, across multiple scales and timeframes, Davoudi et al. (2013) have proposed a comprehensive approach include of a dynamic interaction among transformability, adaptability, preparedness and persistence (TAPP), in which system resiliency is depending on the learning capacity of the communities. It is applied through adapting to the change and progressing into a new state by new ideas and transformation. Thus, the process of how the critical functionality of the system moves from the plan, absorb, recover and adapt is getting involved in the intentionality of human intervention in the crisis situations and helps in recovering from shocks seeking potential transformative opportunities that emerge from the change (Abid 2016).

Resilience as a social feature the second group of studies focuses on resilience associated with behavioral reactions of societies, institutions and economy, examined by assessment of institutional, social and economic variables in both spatial and non-spatial conditions (Rafieian et al. 2011).

Resilience as a feature of social-ecological systems four critical factors are important to create resilience in social-ecological systems (SES): (1) learning to withstand factors such as change, ambiguity and uncertainty; (2) increasing diversity to enhance the ability to learn from accidents; (3) combining different types of knowledge and learning; and (4) creating opportunities for self-organization through strengthening of community-based and participatory governance (Folke 2006).

Dimensions of resilience; general resilience and specific resilience

In the theoretical literature, "resilience" is used in many ways, such as economic, organizational, ecological, social, technical and engineering, supportive infrastructure and communication systems resilience, among which

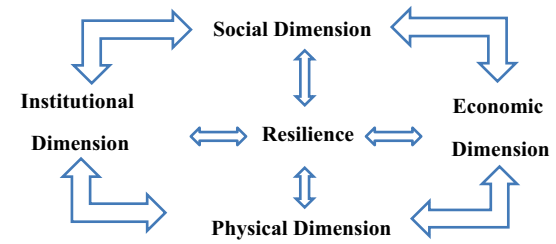

Fig. 2 Diagram of the resilience dimensions

the common aspect is "the ability to withstand, resist and respond positively to the pressure or change" (Bruneau et al. 2003; Cutter et al. 2008). Resilience is a multifaceted entity, including ecological, economic, social, institutional and physical dimensions (Fig. 2).

In the literature about resilience, there are two levels of resilience analysis: general and specific resilience. General resilience concentrates on overall resilience of the system and emphasizes the long-term outcomes, so it can be easily undermined if more attention is paid to the problems of short-term or microscale resilience. On the other hand, specific resilience contributes to specific targeted changes on specific accurate scales and addresses the relationship between the status of the system and a particular disorder, i.e., resilience of something against something else (Garcia 2013).

Resilience of a system is designated as targeted and general resilience (Walker and Salt 2006). In contrast, the specific resilience is interpreted as "from what to what," such as the resilience of a specific system that responds to a known chaos, e.g., the reaction of ecosystems and humans to the rise in temperature in the urban heat island phenomenon. General resilience refers to overall resilience of a system to resist unpredictable disturbances without emphasis on any particular type of shock or variable system. An example can be the total capacity of a city to cope with unpredictable rapid global changes. Specific resilience refers to resistance of something against something else, e.g., the resilience of agricultural production to drought; but in general resilience, there is no concentration on a particular kind of disorder or specific aspect of the system that may be affected. In their article, Walker and Salt (2006) explained that although specific resilience is important, it is not enough alone and, in fact, it would eliminate the general resilience of the social-ecological system because over-emphasis on specific resilience tends toward less diversity in the whole system, lower resilience and less responsiveness. A remarkable point about general and specific resilience is to understand that a system can be resilient on larger scales, while it is not resilient on smaller scales or vice versa. These maladaptive processes show that the resilience of complex adaptive systems should be considered as a feature of the system. The main question about specific resilience is how system responds to a particular type of shock or disturbance and what features of the system can be improved to prevent certain thresholds from being exceeded. In *general resilience*, the system is considered and addressed as a whole with the assumption that there may be new shocks with responses in the system, which are not identified and associated with general resilience. Therefore, it seems that it is necessary to examine the resilience of a system by its general resilience before the assessment of specific resilience concerning certain changes and disorders.

The background of resilience thinking in global literature

Appearance of resilience thinking from ecology science to other sciences such as urbanism

Resilience thinking has been increasingly studied and evaluated since the 1970s with the work of Holling (1973), the Canadian ecologist. Then, it turned into an important theory in many scientific fields from ecology (Colding 2007; Alberti and Marzluff 2004) to economics (Rose 2007), psychology and social sciences (Walker et al. 2004; Ernstson et al. 2010a, b) as a significant research topic toward sustainability. In recent years, resilience thinking has undergone four stages after integrating with social sciences and urban planning literature:

Stage one: Resilience initially appeared as an ecological concept in the theoretical literature (Holling 1973).
Stage two: The system resilience then emerged as a concept in the social sciences (Walker et al. 2004).
Stage three: At the beginning of this stage, urban resilience was considered a social-ecological system (SES) and then concerned with its economic dimension. Accordingly, a series of extensive studies was dedicated to social resilience, economic resilience and ecological resilience in urban systems (Taşan-Kok et al. 2013). The emergence of the term "urban social-ecological system (SES)" resulted fundamentally from a new approach to urban ecology which introduced cities as open living systems and as a combination of social-ecological systems (SES); thus, the study of human relationships as an integral part of urban systems entered urban ecological studies and computations (Folke 2006; Grimm et al. 2000). In the context of modern urban resilient thinking, ecology provides the possibility of integrating human and ecological factors in urban systems, understanding the interactions between them and developing sustainability strategies with respect to identified interactions. Many researchers of urban studies have clearly pointed to the use of resilient thinking in social-ecological systems (SES) such as cities (Walker and Salt 2006; Ernstson et al. 2010a, b; Walker et al. 2004).

Stage four: At this stage, it was attempted to find the principles for the concept of resilient cities; the research emphasized the compatibility of the urban system with

environmental hazards and a holistic approach to resilience in urban systems (Godschalk 2003; Chelleri and Olazabal 2012).

The impact of resilience on cities can be seen in the Rockefeller Foundation 100 Resilient Cities Program (100 RC) (T.R. Foundation 2013) or in the Asian Cities Climate Change Resilience Network (ACCCRN 2014). Both foundations emphasize the need to develop and implement adaptive strategies toward changes in the twenty-first-century cities, which help determine vulnerabilities and support urban neighborhoods to stay resilient in response to future dangers. In the research, e.g., the Rockefeller Foundation 100 Resilient Cities Program (100 RC) (2013) and ACCCRN (2014), resilience is seen as an important feature of the urban system, which enables the system to mitigate the risks (external[1] and internal[2] revolutions), recover from failures quickly, learn from undesirable and unwanted situations and reach a stronger state than the previous one. In a comprehensive conclusion recently made by the Rockefeller Foundation based on the theoretical literature of resilience thinking in urban systems, many remarkable points are raised. For example, approaches that focus on systematic thinking and the systems are related to resilience thinking (The Rockefeller Foundation 2014).

Most of the existing approaches address such thinking on the scale of smaller regions within cities and rural areas, instead of considering resilience thinking on an urban scale, which has led to the emergence of dispersed approaches and independent planning and thinking about systems on different scales. Consequently, urban governing structures affecting the performance of the system on a macroscale are developed regardless of resilience thinking. According to the Rockefeller Foundation's findings, seven urban qualities are introduced on both scales of cities and individual systems that contribute to resilient city systems. The point neglected in this research is a comprehensive and general framework, which combines physical dimensions of cities with those that affect human behavior subtly, to explain a resilient city or system. The factors and application of resilience thinking in urban planning theories are still a challenge being investigated (Pizzo 2013; University College Dublin 2013).

In a thematic category, resilient thinking is applied in the urban literature regarding topics such as urban ecosystem services[3] (including green and open spots) (Ernstson et al. 2010a, b; Alberti and Marzluff 2004; Colding 2007), resilience in planning action, spatial planning, metropolitan planning, land use, urban hazards and natural disasters (Shah and Ranghieri 2012; Albers and Deppisch 2012; Colding 2007), as well as the resilience of regional economy and its relation to economic theories, practices, organizations and agencies (Rose 2007). Resilience thinking in transformation of the urban system is also studied in terms of technological changes (Smith 2010; Hodson and Marvin 2012). In the research, a few studies have been devoted to integrating all these issues (such as Chelleri and Olazabal 2012). Most of the proposed approaches are based on ecosystem, economic dynamics and planning action. Resilience thinking has been applied in different orientations in the scope of planning and urbanization including spatial planning and climate change (Adger et al. 2005; Albers and Deppisch 2012), urban ecosystem and land use (Colding 2007), city transformations and urban resilience (Ernstson et al. 2010a, b), comprehensive multifaceted approaches to urban resilience (Chelleri and Olazabal 2012), resilient cities and natural hazards (Godschalk 2003; Richard et al. 2003), macro-planning of metropolises and resilience. The number of studies that emphasize semantic dimensions and frameworks of the concept of resilience thinking in the theory of urban planning is on the rise. New approaches such as "resilient city" and "resilient planning" are two examples of the research despite ambiguity in the concept, despite adaptation aspects of semantic concepts of resilience thinking in practice and despite its practical aspect (Pizzo 2013).

Although resilience thinking has been long used by scientists in various fields of science, it was first applied in regard to global environmental change at the Johannesburg World Summit on Sustainable Development in 2002. At the meeting, both issues of sustainability and resilience were introduced as preventive principles of using resources, facing the risks ahead, avoiding vulnerability and promoting environmental integrity in the future (Adger 2003). So resilience can be seen as an indispensable approach to sustainable development challenges, and it plays a key role in achieving sustainability (Chelleri and Olazabal 2012) and providing a potential for bridging the gap between interdisciplinary fields of natural, social and political sciences. It must be noted that resilience thinking is still at the discovery stage, but many scholars and thinkers are discussing its uses (Chelleri and Olazabal 2012; Richard et al. 2003; Bozza et al. 2017).

[1] E.g., economic sanctions and terrorism.

[2] E.g., earthquake in Bam, Iran, measuring 6.6 on the Richter scale in 2003.

[3] In the early 2000s, the concept of ecosystem services was defined and categorized into four categories by the Millennium Ecosystem Assessment (MA): "The ecosystem services include four general categories: (1) procurement services, e.g., water, fruit and food production; (2) regulatory services, e.g., climate and disease control; (3) supportive services, e.g., food cycle, crop pollination; and (4) cultural services including recreational and spiritual benefits" (Millennium Ecosystem Assessment 2005). The diversity, continuity and spatial distribution of homogeneous structural elements of the city, originated from ecosystem services, are important dimensions of resilience in cities.

Reflection about resilience thinking in urbanism researches

Resilience in the city, entitled "urban resilience," is defined as the capacity of cities to continue their activity under extreme pressure regardless of the type of shock or stress they face, so that the people who live and work within the cities, especially the poor and the vulnerable, can survive and grow steadily (The Rockefeller Foundation 2014). In recent researches, the latest definition of urban resilience refers to the ability of a city system and all of its social-ecological and socio-technical networks on spatial and temporal scales to maintain or quickly return to good functioning while facing an imbalance: a system that adapts to the change or rapidly changes due to its resilience feature (if the system restricts the capacity to adapt to current or future changes) (Meerow et al. 2016).

The city itself is also an intricate concept. A city is a dynamic and complex process of various scales of space and time (Alberti et al. 2003); it is simultaneously a social phenomenon and a physical transformation of the urban form that manifests the realization of human connection with the environment. Urban resilience has recently been recognized by the Committee for the Millennium Ecosystem Assessment as an important knowledge of urbanism and urban landscape, which requires further research (Chelleri and Olazabal 2012). The urban form is constantly changing and such change and dynamism make it a challenge to understand the forces causing changes. Therefore, understanding the role of time and the process in which conditions change the urban form is an important part of urban resilience. The spatial structure of a city and its infrastructure are critical in this study (Alberti et al. 2003). Current research on urban resilience emphasizes urban compatibility, adaptation and reinforcement of the urban system to reduce the risks and to adapt to the ever-increasing changes in the present age. In Iran, most researches on resilience have focused in psychology, social sciences and the environment. The studies that addressed resilience in urban environmental dimensions have usually assessed the distribution pattern of ecosystem services such as gardens and urban green spaces or investigated urban resilience in relation to natural disaster management and suggestions of indicators to measure urban resilience.

While most research topics rely on environmental dimensions, adaptation and reduction in natural hazards such as earthquake threats, global warming and climate change (Rafieian and Sheikhi 2015), some studies focus on planning and management of the risk of natural disasters in the framework of resilience thinking through modeling. This emphasizes the issue of accidents threatening a system more than the resilience as a feature of the urban system (Rafieian et al. 2011). Many scientists working on accident management research conduct studies on urban capacity for post-accident recovery through resilience thinking (Cutter et al. 2008; Bruneau et al. 2003). However, this is only one of several research areas used concerning resilience in urban environments. In the 1990s, urban resilience appeared in spatial planning discussions. The scheme was based on how urban activities exposed to high pressure in natural and environmental disasters could continue operating in resilient urban neighborhoods and cities after the incident (Eraydin and Tasan-Kok 2013).

According to the research results of the Resilience Alliance at Gothenburg, Sweden in 2007, four significant research areas were identified about resilience of the urban system. Overlapping with each other, these four areas include: (1) research about urban resilience and governance networks, organizations and administrative structures; (2) research about urban resilience and social dynamics, population size, human capital and justice; (3) urban resilience and dynamic flows of production, distribution and consumption cycles; (4) research about urban resilience and built environment, ecosystem services in the urban landscape (which searches for the pattern of urban form) and spatial relationships between the constituents of urban environment and form. In these four areas of research, an important point is that they are all under the control of both general resilience, of an urban system as a whole, and specific resilience of the urban system components (Resilience Alliance 2007). Due to insufficient studies, urban resilience requires further research in three main realms: (1) the local-spatial research on urban systems and the need to expand the spatial morphology that plays a leading role in key features affecting urban form and resilience systems; (2) the institutional and organizational research on urban systems and the need to understand the spatial form of the city with the aim of developing organizational support for the design of a resilient urban system; and (3) the discursive research on urban systems where it is required to critically analyze the basic concepts and hypotheses, such as supporting urban social-ecological systems in recent debates on sustainability (Marcus and Colding 2014). Nevertheless, given a few studies and researches on the relationship between social systems, ecology and urban resilience with the context of morphology and urban spatial structure, it seems like a highly innovative and novel subject in the global literature (Garcia 2013; Marcus and Colding 2014; Feliciotti et al. 2016a, b). According to Hanson's definition, the spatial morphology is a study on urban pattern and form (Hanson 2001). The term "built environment" is also applied to illustrate the relationship between the built and natural environment that is used to define the social-ecological system where the built environment is considered as an artifact in terms of the interference of culture and nature, being affected by both (Hassler and

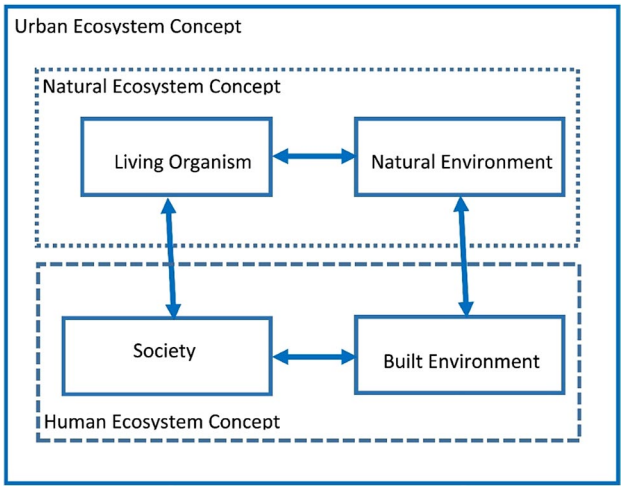

Fig. 3 Diagram of urban ecosystem concept includes the components of the human ecosystem concept and the natural ecosystem concept based on Grafakos et al. (2016)

Kohler 2014). Therefore, in urbanization, there is a research deficit in the development of knowledge, which would allow the understanding and evaluation of the resiliency feature in a metropolitan system in economic, social, organizational, institutional, environmental and formal dimensions at varying levels. This means that much more research has been done on social resilience in the city than on resilience of spatial structure and urban form. Such deficit is most evident when trying to find operational tools for the assessment of resilience in cities.

Urban system as a context for resilience thinking in urban resilience

At first, it is necessary to give a definition of the system from an ecological and then urban planning point of view in order to provide a better understanding of the urban system and its relationship with resilience thinking. The concepts of ecosystem and system were first addressed in ecology[4] (Walker et al. 2004). Then, they entered urban research under the title of "urban system" and applied to cities. The concept of system is a key notion: A system consists of different parts. The characteristics of the system appear through the communication and interaction between its different parts. As soon as the elements and components interact with each other to create a system, their function within that system would be completely different from when they operate as independent entities (Pickett et al. 2013). In the Oxford English dictionary, a system is defined as "a complex whole and a set of things or parts related to each other or as a set or group of interrelated, interdependent components that form a complex unit" (Taylor 1998). Urban systems are generally heterogeneous, and this heterogeneity results from the combination of natural and built elements, e.g., a combination and distribution of a variety of buildings, pavements, green spaces and so on. Social-cultural characteristics together with the behaviors of institutions, organizations and individuals create a large part of this urban heterogeneity, resulting from their continuous change (Cadenasso et al. 2013). Associated with natural ecosystems, social elements and built environment, the concept of urban ecosystem is shown in the diagram as a part of the urban complex in the form of a social-ecological system (Fig. 3). The urban socioeconomic system is directly connected to the ecological system, which provides multiple services to human societies, economies and cities through its three main functions: source function, service function and sink function.

The ecological system steadily changes just as much as the socioeconomic system evolves. The cycle of these developments is unpredictable and responds to a wide range of internal and external flows. An integrated way to understand these multiple changes is the examination of socioeconomic and ecological systems in terms of a system that works through multiple spatial scales and time frameworks (Pisano 2012). Ecologically, an urban zone is thus a specific ecosystem with its particular function. An ecosystem is defined as a biological complex of the relationships of living organisms with their physical environment, and the concept is clearly adapted to urban areas. Urban ecosystems are interconnected systems of man-made services and the natural environment, and it is important to understand the complexity of the urban system so that urban planners, decision-makers and social organizations perceive a common concept of natural ecosystems and urban infrastructure in the urban built environment and employ it specifically for resilience projects.

A remarkable point in this regard is to address the ecosystem as an approach. The ecosystem approach is a theoretical approach that helps urban experts create chaos in the network of variables and their relationships. This approach is a result of biology that has helped biologists understand the complexity of organisms and their relationships with the environment (Van Bueren 2012). The ecosystem approach can be used to describe urban systems with all their complexity and can help identify opportunities to improve the sustainability of urban living. Since resilience thinking involves a systematic thinking (Pisano 2012), it is necessary to redefine the city as an urban system. An urban system is a complex system of different subsystems of different dimensions, related to each other (Alberti and Marzluff 2004; Ahren 2012). Just as living creatures can be considered as systems, human artifacts such as cities and their regions

[4] The English botanist Arthur Tensley was the first person who expressed the concept of ecosystem in 1935 (Walker et al. 2004).

can also be thought of as systems. A city can be considered a system because different land uses are interconnected through transport and other circulating flows (Taylor 1998). Hence, urban systems are an integrated set of natural and human subsystems. In terms of a physical system and urban form, the urban system encompasses main elements of the city's structure: main roads, main urban buildings (providing main services on the scale of the city) and green public urban spaces (Godschalk 2003). To perceive resilience thinking, the city should be considered as an urban system (Van Bueren 2012). In an adaptive urban system, if the components of resilience are coordinated together, cities can be deemed to be resilient and thus they will not be vulnerable or fragile.

The analysis of urban systems as resilient cities

A resilient city is a sustainable network of physical systems and human societies. The physical system encompasses: (1) elements of the natural environment, including water, soil, topography, and vegetation; (2) elements of the built environment or man-made elements, including constructed routes and roads, buildings, infrastructure, communications, urban facilities and the structure of a city, in general. In fact, the physical system of the city acts as its body, playing the role of bones, joints and muscles. In a disaster, the physical system must be able to survive and act under extreme pressure. If it cannot be recovered after damage, the skeleton of the city is lost. A city without a resilient physical system will be highly vulnerable to disasters (Godschalk 2003). Therefore, a city is deemed resilient when it can simultaneously balance the ecosystem and human functions. It should be able to adapt to uncertainty and to unexpected events, be flexible, preserve existing and potential opportunities and invest in them (Eraydin and Tasan-Kok 2013). As a built environment constituted of social-ecological systems, cities are also complex adaptive systems (Alberti and Marzluff 2004; Ahren 2012) which require confronting the socio-ecological threats. Therefore, resilience is a key tool for improving the adaptability capacity of the built environment of cities. Despite understanding and assessing the dynamics of changes in the built environment of cities, the urban resilience capacity against chaos and disturbance is a topic that has been a concern in recent urban studies (Garcia 2013). Resilient cities can withstand extreme shocks because they are designed to be safe from the effects of natural or technological hazards and are established by principles, which are not halted by dangerous forces (compared to the past experiences). They can also adapt to different levels of sustainability because they consist of interconnected social groups and living systems as well as sustainable physical and economic systems. Many recent studies have deemed the development of resilient societies necessary (Christopherson et al. 2010; Alberti et al. 2003). A resilient city is a sustainable network of physical systems and communities. Physical systems, environmental and built components of the city include roads, buildings, communication facilities, soil and geographic features. During a crash, physical systems should be able to survive and function in severe conditions. In an accident, communities must be able to rescue and perform in critical situations resilient systems (Godschalk 2003).

Urban systems need to be resilient not only physically and formally, but also psychologically and socially, so organisms of the urban system (the human beings) must also be adaptable and resilient. Therefore, the role of the city is twofold: (1) creating a system which responds to change; and (2) creating a system that offers behavioral adaptation of people to change, which is a challenge for cities because humans are simultaneously the cause and the solution for their vulnerability (Dekker 2014). From this perspective, urban resilience can be divided into two general categories: (1) structured and (2) non-structured. In this sense, for example, the security of essential infrastructure is defined by structural factors including tangible and cybernetic physical assets in a metropolitan area. The position and capability of structures and systems shown in a specific area may include the position and capacity of bridges, roads, telecommunications lines and pipelines. Non-structural factors include human abilities and assets. Organizations associated with effective planning and management of infrastructure, services and products provide these types of factors. Examples include public–private partnerships, planning processes, methods of responsiveness, and implementation and training (Rezaei 2013). Given the categorization of urban socioeconomic resilience based on human abilities, non-structured resilience and urban local-spatial resilience fall into the category of structural resilience.

Beyond general explanations and the roles conceived for resilience thinking, the application of this approach, especially in the urban system, requires attention to three

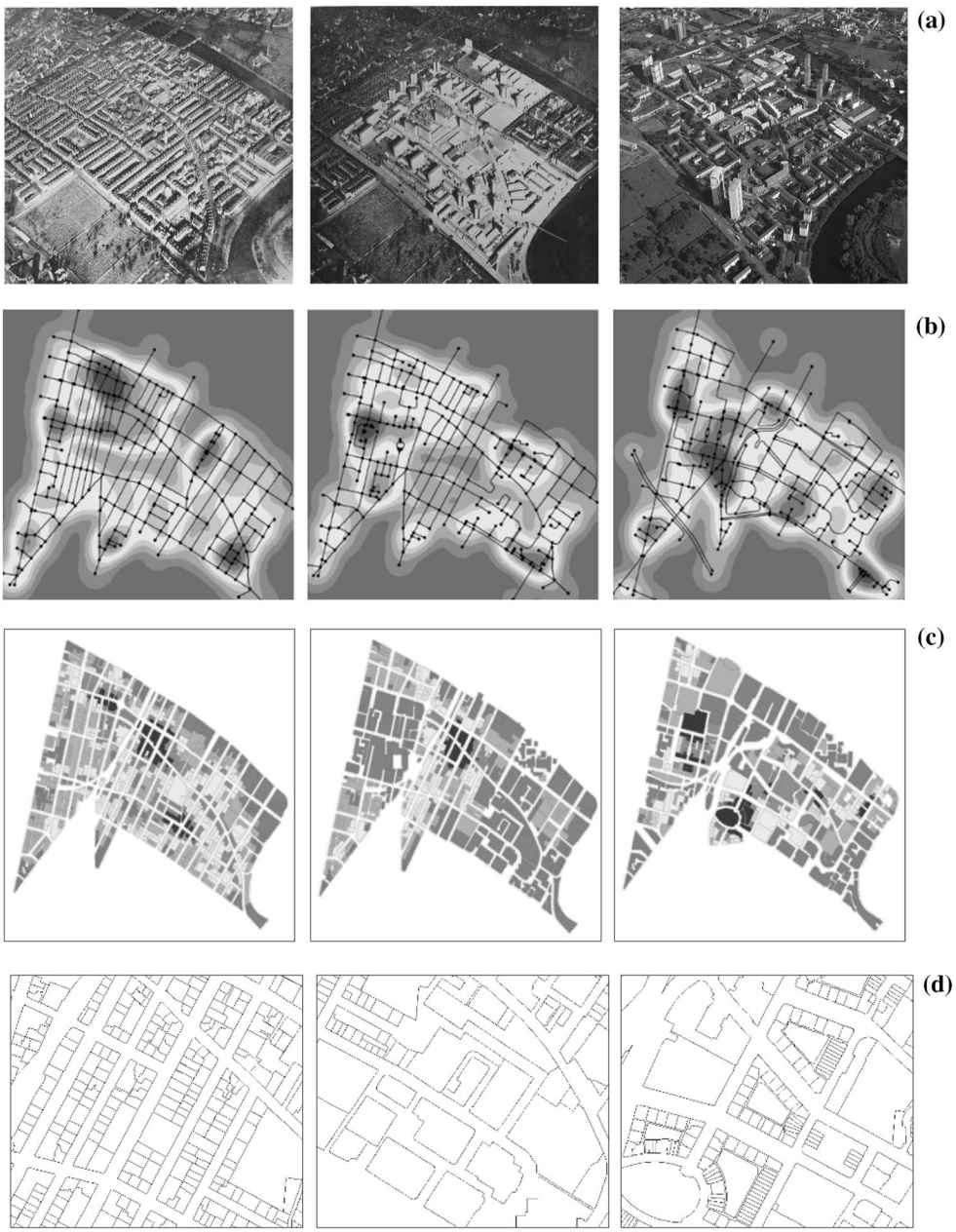

Fig. 4 Considering the local-spatial resilience indices in Glasgow, Scotland. **a** The extent of multi-functional changes in the city center, **b** the average length of streets and the number of intersections, **c** changes in the number of main services and equipment of the city, **d** changes in dimensional geometry and size of urban blocks (Feliciotti et al. 2016a, b)

important realms: (1) facing social issues, (2) facing the uncertainty and limited scope for its controllability, and (3) avoiding undesirable steps that restrict reversibility of the urban system to the stability (Eraydin and Tasan-Kok 2013).

It is obvious that resilience is not a definite, certain, finite step, but it is a "process," in which an urban system becomes ready to face changes and risks. Achieving sustainable and resilient cities requires an integrated and comprehensive

approach that consists of a mix of planning, policies, rules, regulations and investments. Delay of a timely action can lead to problems such as emergence of and confrontation with high-risk situations.

Considering the published results of a case study: the experience of Glasgow city

In order to clarify the theoretical issues mentioned above, a relevant field research is presented in this section. Examples of global resilient cities have been studied in terms of CO_2 mitigation and capability of hazard adaptation in different cities (Pelling and Wisner 2009). However, it must be noted that assessment of resilient cities still requires further research, especially in terms of morphology and local-spatial dimensions. An academic study was recently conducted to investigate local-spatial resilience of urban areas considering the local-spatial resilience indices in Glasgow, Scotland (Fig. 4). Five local-spatial resilience indices including diversity, redundancy, efficiency, modularity and coherence were investigated in an analysis of urban form changes within a given period and the results indicate an increase in urban resilience in the city (Feliciotti et al. 2016a, b). Subsequently, the urban development of the city center of Glasgow was studied through three phases of the master plan, from a period prior to World War II to the present. Five urban local-spatial resilience indices were assessed to achieve the trend of resilience in these neighborhoods, by investigating the relationship between local-spatial resilience, urban design and analysis of changes in the urban form. The indices were defined in three phases of the master plan. The changes in urban form and structure, and their impact on the overall orientation of local-spatial resilience of the city center of Glasgow were analyzed before and after implementation of the phases. First, the definitions of the indices were presented:

1. Diversity index: Diversity in the structural elements of urban constitution provides a framework for strengthening the multi-functional nature of the urban system and promotes the interaction between its components. The feature of diversity allows the system to create space for innovation while maintaining relative stability in a variety of economic, social and cultural settings.
2. Redundancy index: In the system, this index refers to a feature that provides a form of insurance against damage or failure through the presence of multiple components or paths with similar performances or backup functions (Ahren 2011); so it represents the degree of abundance of internal system components.
3. Coherence index: It is represented as a feature in an urban system in terms of urban context. Whether in one area or in conjunction with its background, the integrated continuous urban context facilitates transport of people and goods. The structure of connections determines the interface points between the urban texture elements and the location and severity of activities.
4. Efficiency index: It describes structural complexity of a system on the scale and needs of each section within a system. Concerning the system form, the efficiency index requires a strong correlation between the elements on smaller and larger scales of a system. This is analyzed considering the distribution of urban blocks, components and their relationship within the urban context at several morphological levels of access to energy and resources in an urban system.
5. Modularity index: A modular system is identified through distinct measurable units that are independent structurally and functionally, while coherently linked to other units at the same time. It means that the entire system's units will not be involved in case of a defect within an independent unit, so that the independency provides a basis for innovation in sharing the deficiency with other sectors under the allowable conditions of the system (Feliciotti et al. 2016a, b).

The indices were then analyzed in relation to local-spatial resilience surveys. It means that the diversity index is examined for the extent of multi-functional changes in the city center of Glasgow in terms of the number of shops, services and industrial land uses, equipment and residential facilities both in vertical and horizontal densities as changes in land use and zoning principles during the given time period (Fig. 4a). In addition, the number of main services and equipment of the city, such as a variety of public services and equipment (including large-scale industrial or cultural services like city theater) are studied. Moreover, the communication network including the average length of streets, the number of intersections, old and new streets is studied in regard to the redundancy index during three phases of implementation of the master plan (Fig. 4b, c). Changes in urban blocks were investigated regarding the measure of the modularity index as an indicator for the assessment of independent measurable units of the urban system, which are related to the integrated urban entity but are also independent. Thus,

changes in dimensional geometry and size of urban blocks were studied in terms of fine or coarse grading (Fig. 4d).

Further and separate research is suggested to investigate the coverage density and its relationship with local-spatial resilience indices. A study on the size of urban blocks was employed to measure correlation: Smaller sizes of urban blocks are correlated with increasing connection between them. In regard to the efficiency index, accessibility to energy and resources was investigated within a city system on several morphological scales considering the distribution of urban blocks and components and their relationship to the urban context (Feliciotti et al. 2016a, b). In conclusion, it can be said that the article attempts to examine the relationship between urban forms and resilience, which is a novelty in urban studies. The authors tended to identify and develop the main indices introduced on different scales, so that they can be used for accurate morphological analysis of urban context changes over time, in accordance with the major social, economic and political developments. They suggest that using the results of this study for other areas in Glasgow may be a step toward further developments.

Findings and discussion

Despite initial research on resilience several decades ago, there has not yet been a comprehensive and operational understanding of this concept, particularly concerning urbanization. Many of the definitions of resilience thinking are derived from existing cognitive inclinations, fundamental conceptual differences and approaches, and perspectives focused on research about ecological, social systems or a combination of both. Understanding the difference between definitions of resilience from an ecological point of view (in purely natural and biologic systems) and from the urbanization point of view (including urban systems with complex functions, different from natural systems and living organisms) is very important. In new ecological definitions, which are particularly close to the urbanization point of view, resilience thinking does not necessarily refer to the ability of a system to go back to the past and the previous equilibrium point after the disruption or shock. The previous path and equilibrium point may disappear partially or completely after a change, shock or disturbance due to numerous reasons. Alternative paths are likely to appear. All these scenarios and probable options can change the path of the system, which must be considered.

In contrast, engineering definitions believe in an equilibrium point in the system and consider the resilience as preserving existing structural conditions of the system or the speed of the system's return to its previous state (prior to the pressures and changes). In other words, the long-term recovery process after an accident aims at quick rehabilitation or return to the previous state in order to maintain the balance. However, in urban resilience approaches, such as ecological definitions, the concept of adaptability with changes varies with the system's ability and capacity of self-reorganization and conservation of fundamental structures, which may lead to a new equilibrium point that can modify the structure or function of the system. In other words, this approach embraces the concept of sustainability based on long-term survival and more sustainable use of system resources without losing quality of life.

Given the abundance of definitions of resilience, a study about different definitions indicates the need for further research on resilience in various branches of science, especially in urban planning. The literature review shows that resilience thinking leads to the emergence of resilient cities through the development of appropriate capacities of the urban system based on a combination of "absorbing disturbances and achieving a balance," "self-organizing" and "increasing the capacity for learning and compatibility," but it is necessary to change the current trend to a systemic approach regarding the concept of the city. On the other hand, urban resilience can be studied in four dimensions: social resilience of the urban system, economic resilience, organizational and institutional resilience, and local or biophysical resilience (natural and built environment in the urban system). A fine point to be considered regards resilience properties of the urban system, which should be immediately identified in terms of social, economic, institutional or biophysical dimensions. For instance, an urban system may be economically but not socially resilient. Therefore, one of the essential requirements for starting a research project on urban resilience is to consider the dimensions of urban resilience.

Finally, it is very important to pay attention to both levels of general and specific resilience. General resilience refers to the overall resilience of a system in order to withstand unpredictable disturbances, which does not emphasize any particular type of shock and focuses on long-term outcomes. However, in specific resilience, the main question is how these variables respond to a particular type of shock or disturbance and what properties of the system can be improved to prevent certain thresholds from being exceeded. Hence, it seems that assessment of resilience properties of a system essentially requires attention to its general resilience before examination of the specific resilience concerning certain changes and disturbances.

Conclusion

Considering the literature review of urban resilience, the research results show that while most research topics rely on environmental dimensions and reduction in natural hazards (such as earthquake threats, global warming and climate change) and emphasize the social urban resilience, inadequate studies related to spatial morphology and urban spatial structures exist, and the need for further research on that is evident. A recent research on urban resilience in urban form (a novel topic in urban resilience studies), the experience of Glasgow is addressed as an example of application of urban resilience research in this study. It attempts to introduce indices of urban resilience through a particular attitude toward the relationship between urban form and urban resilience; although it is an effective step in this regard, it also needs further research to identify more indices. The authors identify and develop the main indices introduced on different scales, so that they can be used for accurate morphological analysis of urban context changes over time, in accordance with the major social, economic and political developments. It is thus suggested that using the results of this study may be a step in further research in other urban regions, aimed at clarification and measurement of the concept of the urban local-spatial resilience specifically in terms of urban morphological and spatial aspects.

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