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Urban Local-Spatial Resilience: Developing the Key Indicators and Measures, a Brief Review of Literature

Fariba Gharai*
Mohammad Reza Masnavi**
Mona Hajibandeh***

Abstract

Cities are making significant impacts on the environment and urban sustainability. Problem statement and research objective: Resilience in cities is seen as an important goal towards sustainability. In the same manner, the urban resilience and its key measurement in the city structure gets a higher priority. Moreover, considering measures of resilience is specifically indispensable for policy makers and supports the process of decision making in the cities. Despite advances in this field in recent years, there is still an essential need to provide clear ways to measure and quantify the urban resilience in terms of spatial aspects.

Research questions: these questions are raised in this research:

1) what are local-spatial indicators of resilience?

2) what is the relationship between resilience and spatial organization of the city?

3) what is the role of spatial organization elements of the city in urban local-spatial resilience?

Research Methodology: A review of literature is used to identify the key elements in the measurement of resilience in relation to the spatial structure of the city. Then, the analyses of the operational definitions and the major indicators have been done separately.

Research results: Results and findings demonstrate the key indicators in the measurement of urban spatial resilience based on the urban spatial structure components including a) diversity, b) connectivity, c) redundancy, and d) robustness features as the major indicators for the cities spatial structure resilience.

Keywords

Urban local-spatial resilience, Key indicators, Resilience measures, Urbanism.

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**. Associate professor of Architecture, Faculty of Architecture and Urban Studies, Art University of Tehran. Gharai@ art.ac.ir

***. Professor of Architecture & Environmental design, Graduate Faculty of Environment, University of Tehran. masnavim@ut.ac .ir

****. Ph. D. Candidate in Urbanism, Department of Architecture and Urban Studies, Art University of Tehran. monahaji@gmail.com

Introduction

The environmental problems associated with urbanization are rooted in both ecological and urbanism realms (Masnavi, 2013), which has led to interdisciplinary research fields in these sciences. One of these research areas is the resilience of urban systems. Cities have a significant impact on the environment and the promotion of sustainability and resilience in cities and human settlements is a priority (Masnavi, 2011; Chelleri & Olazabal, 2012). Hence, measurement and study of urban resilience are important in cities. However, despite significant advances in recent years, existing methods for measuring urban resilience have only analyzed it in specific disorders environmentally in terms of resilience engineering or ecological resilience (Suárez, et al, 2016). Therefore, despite the introduction of some indicators for measurement of urban resilience based on literature review, it is necessary to view this issue from different perspectives based on urban resilience dimensions, such as social, economic, organizational and institutional and local-spatial resilience. It should be taken into account that the study about the local-spatial dimension of resilience needs more investigation through further research (Suárez et al 2016; Sharifi & Yamagata, 2016; Meerow, Newell & Stults, 2016; Feliciotti, Romice & Porta, 2016). Although research on resilience indicators has generally begun long time ago, the set of local-spatial indicators of urban resilience has been recently noticed by urban scholars. The research on resilience indicators still faces numerous challenges, which the present study attempts to clarify through investigations. Thus, these questions are raised in this research: 1) what are local-spatial indicators of resilience? 2) what is the relationship between resilience and spatial organization of the city?, and 3) what is the role of spatial organization elements of the city in urban local-spatial resilience? In various references, a variety of indicators are presented to determine the resilience as a whole, which are general and holistic, mostly related to resilience engineering or resilience of socio-ecological systems and rarely associated with urban systems and "urban resilience". For example, important indicators of a resilient system generally include: 1) knowledge and learning, 2) change against disturbance, 3) self-reorganization, and 4) diversity (Barthel, et al, 2013). Other indicators also consider a specific resilience for specific disturbances or resilience of a part of a system. In this study, the local-spatial indicators of "urban resilience" are explained considering the urban system as a whole, according to the latest research, and it is argued that these indicators must be applied to help planners understand how to enhance the ability to plan and prepare for absorption of disturbances, recovery and adaptation to destructive incidents. According to the literature review, studies on development of urban resilience indicators have increased, remarking it as a significant issue in scientific and political realms that affect the future urban development (Sharifi & Yamagata, 2016). Fig. 1 shows a diagram of the research conceptual model.

Research Methodology

At first, a theoretical framework was prepared for the resilience of urban systems in accordance with literature review and the studies, which addressed resilience thinking in regard to the city and urban system are noticed in terms of resilient cities and resilience of urban systems. The theoretical literature and information were systematically collected through library research and credible databases such as Scopus, Web of Science and Science Direct. In the next step, components of urban systems and spatial organization of the city, resilience thinking and indicators of urban resilience were studied, evaluated and analyzed. Then, the indicators focusing on local-spatial dimension were derived and developed to measure the resilience of urban systems. Consequently, the indicators of resilience assessment were proposed in regard to the components of spatial organization of the city including 1) major urban centers, axes, and functional zones, 2) the main network of transportation corridors, 3) urban zone

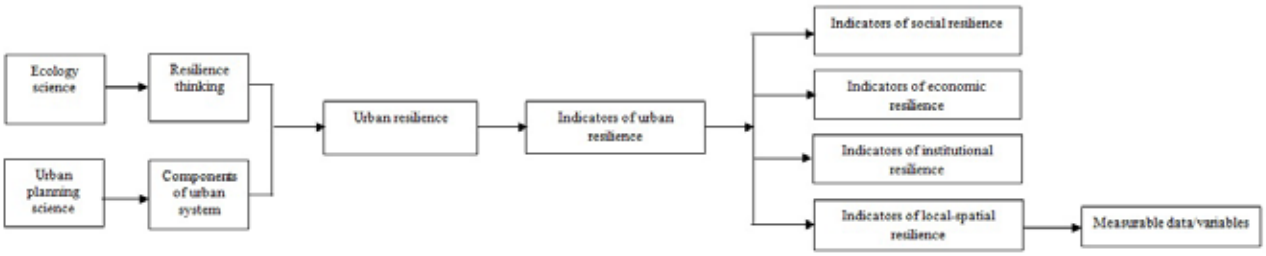

Fig. 1. A diagram of the research conceptual model. Source: authors, 2018.

consisting of urban blocks, and 4) natural green open spaces, using capacity development tools like RAP based on recent research on classification of resilience indicators and the operational definitions of indicators and their measurable data were presented and analyzed.

Urban Resilience Thinking and Categorizing the Indicators

Resilience thinking has been variously defined and some of its conceptual circles are formed. However, there is a conceptual agreement on this subject. According to Alberti et al, whose definition of resilience is oft-cited in scientific research, resilience is "the extent to which a system is capable of absorbing risks and reorganizing itself". Accordingly, resilience is a combination of "absorbing disturbances and achieving a balance", "self-reorganization" and "increasing the capacity for learning and adaptability" (Alberti et al, 2003). According to the latest definition of urban resilience in recent researches, the ability of an urban system and its whole socio-ecological and socio-technical network in spatial and temporal scales is called resilience, which attempts to maintain or quickly return to good functions when faced a disturbance; a system that adapts to the change, so that if the system restricts the capacity to adapt to current or future changes, it will be quickly changed due to its resilience characteristic (Meerow, Newell & Stults, 2016). The common aspect of all definitions of resilience thinking, which should be considered, is the ability or capacity to absorb disturbance and risk, adapt to changes and improve and maintain inherent characteristics and structures of the system; in addition, resilience is mostly seen as the ability or flow rather than a result. Table 1 presents a categorization of urban resilience indicators in accordance with resilience dimensions.

As presented in the table, the indicators are general and the evaluator is not able to measure them for judgment. However, the evaluation has a successful outcome when it is based on spatial analyses and can be quantified and objectified. In the next step, the urban resilience indicators are developed and presented focusing on urban local-spatial resilience, which is defined according to Spaliviero (2015) as the design and organization of urban spaces and activities in a way that promotes the maintenance of natural environment. In this study, urban local-spatial resilience refers to an aspect of urban resilience, which relies on urban activities and spaces and is somewhat independent of other dimensions of urban resilience. This dimension of urban resilience covers both natural and built urban environment with an emphasis on activity and space.

The Indicators of Urban Local-Spatial Resilience

Urban local-spatial resilience indicators are directly related to physical and environmental dimensions of the urban system, which associated with main components of the spatial organization of the city. The spatial organization of the city is a reflection of urban

Table 1. Categorization of urban resilience indicators in accordance with resilience dimensions. Source: authors, 2018.

Resilience Dimensions	Resilience Indicators
Social Resilience (Hassler & Kohler, Santos Cruz et al, 2012) 2014;Godschalk, 2003 ;Walker & Salt, 2006; Suárez, Gómez-Baggethun, Benayas, & Tilbury, 2016)	Adaptability or adaptation capacity, connectivity indicator(Different parts of the social system), vulnerability, household and population health, cultural services, reduction of violence and insecurity and urban crime, learning and awareness capacity, diversity of social classes, creativity and innovation, human resource competence and abilities, Timely Accountability, Social Capital
Economic Resilience (Eraydin & Tasan-Kok, 2012; Ernstson, et al 2010)	Livelihoods and viability, urban economic strategies and policies, communication or connection index (different sectors of the economic system), wealth and employment, economic diversity
Environmental/Physical Resilience Olazabal, (Walker & Salt, 2006; Godschalk, 2003 2012;The Rockefeller Foundation, 2014; Alberti & Chelliri & Colding; 2007 ;Eraydin & Marzluff, 2004; Tasan-Kok, 2012; Feliciotti et al, 2016; Sharifi & Yamagata, 2016)	Diversity, connectivity indicator(Different parts of the environmental system), climate and soil health, adaptive design (urban environmental quality index through the role of design and organization of space), urban infrastructure, ecosystem services, (modular) modularity and the ability to measure, Robustness (resistance of elements and physical components of the city, such as roads and buildings), adaptability capacity, redundancy, sustainability, natural capital
Institutional Resilience (Ernstson, et al 2010 ;Barthel, et al., 2013; Suárez et al, 2016)	Institutional skills and structures, decision-making and decision-making policies, integrated management, diversity of organizational levels and inter-organizational communication, connection index (different parts of the system of organization and institutions), adaptability or adaptation capacity, timely response speed

local-spatial dimension, which depends on various interrelations of all forces and factors in the city. These factors may include market forces, activities, urban infrastructure and different services that always have complicated interrelations (Ziari, et al, 2013). The spatial organization is a network whose elements are urban centers (mixed-use commercial, office, cultural, etc. centers on the whole scale of the city and its districts and regions, important transportation routes (main roads and metro lines), important functional axes and major land uses (on scale of the city and its districts and regions) (Center for Study and Planning of Tehran, 2006). Therefore, the spatial organization of the city includes main elements of the city's construction, which are: main roads, main buildings providing major services on the scale of city and public green open spaces (Godschalk, 2003). The city's spatial organization is based on the definitions and description of the city. Fig. 2 illustrates the spatial organization of the city and its major component on an urban scale, according to definitions and explanations above.

According to the literature review, Jack Ahren, the landscape ecologist, classified urban resilience indicators as five urban design and planning indicators including redundancy, (bio) diversity, multifunctionality of urban system, urban ecological networks and transportation, and adaptive design or adaptability; he also remarked a combination of ecological and urban principles to achieve urban

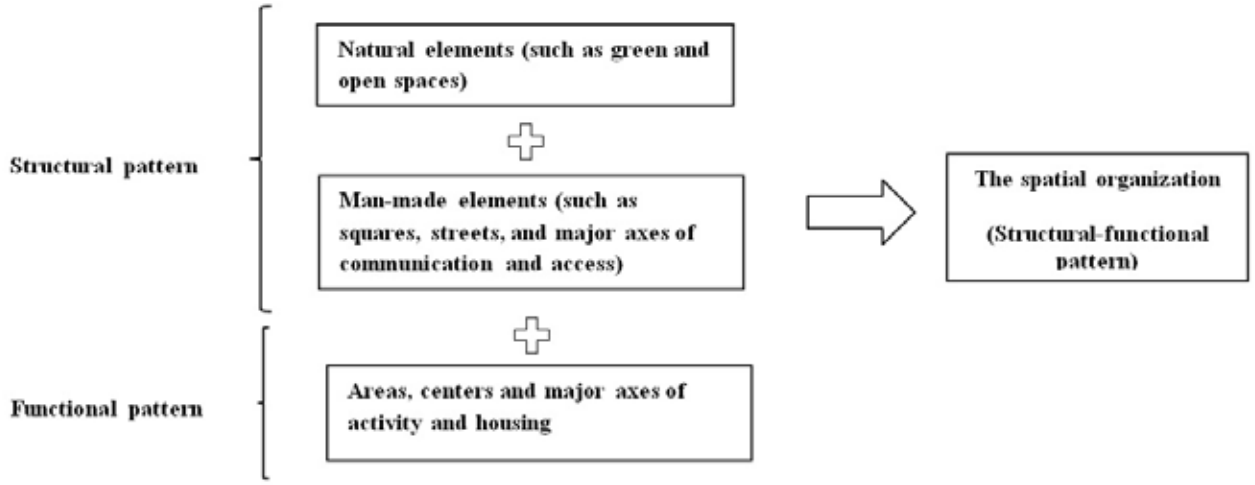

Fig. 2. The spatial organization of the city and its components. Source: authors, 2018.

resilience (Ahren, 2012). Another classification of indicators was derived by Walker and Salt who were pioneers of suggestion and development of resilience indicators (Walker & Salt, 2006). The indicators were investigated for urban applications (Eraydin & Tasan-Kok, 2012; Allan & Ahren, 2011; Bryant, 2011), among which the redundancy, diversity, efficiency, autonomy, connectivity, adaptability or adaptation capacity, robustness and flexibility were applied in cities by common consent (Sharifi & Yamagata, 2016; Feliciotti, Romice & Porta, 2016). Subsequently, four indicators were selected in regard to local-spatial planning of urban disturbances, including: 1) diversity, 2) Connectivity, 3) redundancy, and 4) robustness. They were chosen because 3-5 key indicators were suggested to study the resilience of urban systems on local and temporal scale (Gracia, 2013; Resilience Alliance, 2007), among which these four indicators were the most oft-cited in urban resilience studies (Barthel, et al, 2013; Chelleri & Olazabal, 2012; Eraydin & Tasan-Kok, 2012; Grafacos, et al, 2016; Feliciotti, et al, 2016; Hassler & Kohler, 2014; Marcus & Colding, 2014; Lu & Stead, 2013; Sharifi & Yamagata, 2016; Meerow, et al, 2016) and had the highest compatibility with components of urban spatial organization, so that they could be used for urban applications by urban design researchers. Table 2 presents definitions of these four indicators.

Indicators of urban local-spatial resilience conceptual model based on the spatial organization of the city components

Based on components of urban spatial organization, two structural and functional patterns were proposed for the urban system to apply the indicators in measurement of urban local-spatial resilience. Accordingly, operational definitions, measurable data and challenges of the indicators were assessed.

Diversity and its measurable variables: this indicator is often considered as a key feature of urban resilience in the literature review (Suarez et al, 2016). Diversity is an essential characteristic in urban design literature, because the diversity of land uses and geometry of urban forms leads to vitality, healthier life styles and even economic attraction in the city (Bentley et al, 2010; Jacobs, 2007; Kermona & Tizdel, 2011). In urban spatial organization, major functional axes include a variety of urban functions organized vertically and horizontally within the edge of main streets (Wood & Dovey, 2015). Multifunctional urban spaces promote the diversity, which is essential for absorption of the disturbance

Table 2. Definitions of the four indicators of urban local-spatial resilience. Source: authors, 2018.

Indicators of urban local-spatial resilience	Definitions of the indicators	Researchers
Diversity	Diversity in the structural, constituting elements of urban form provides multifunctionality and promotes greater interaction between components. Diversity allows the system to make room for innovation while maintaining relative stability across different economic, social, and cultural conditions.	Hassler & Kohler, 2014; Sharifi & Yamagata, 2016; Suárez et al, 2016.
Connectivity	An interconnected urban fabric, both within an area and to its context, facilitates movement of people and goods. The structure of connections determines points of contact between elements of the urban fabric and therefore the location and intensity of activities.	Sharifi & Yamagata, 2016; Eraydin & Tasan-Kok, 2012; Ahren, 2012; Allan & Bryant, 2011
Redundancy	Redundancy in systems is a characteristic that provides a sort of insurance to damage or failure through the presence of multiple components or pathways "performing the same, similar or backup functions". It implies a degree of internal variability, as well as functional duplication.	Hassler & Kohler, 2014; Sharifi & Yamagata, 2016; Suárez et al, 2016
Robustness	This indicator is related to the strength of buildings, roads and physical urban elements and means the ability of a system to resist changes and disturbances without failure or loss of performances; it is also referred to as the sustainability index.	Sharifi & Yamagata, 2016; Eraydin & Tasan-Kok, 2012; Bruneau, et al., 2003

and recovery (Sharifi & Yamagata, 2016). The diversity can be studied in two views: spatial diversity that is associated with spatial distribution of urban structural elements and refers to equal public access to basic services throughout the city and reduction of the risk that whole system is affected by a disturbance, and the other, functional diversity, which refers to mixed urban land uses and a variety of open green spaces, e.g. urban gardens and linear or regional parks on various scales, that enhance urban vitality and resilience (Suarez, et al, 2016). However, this indicator seems controversial in relation to other local-spatial components of the city, such as main transit routes and urban zone. The diversity of transportation routes means a variety of roads within the urban zone that forms a network of main and secondary roads. This hierarchical road network reduces the urban resilience (Chelleri & Olazabal, 2012). Consequently, an integrated network of roads in the city is proposed versus the hierarchy of roads, which is often criticized by urban designers (Marshall, 2005). On the other hand, the use of fine- and coarse-grained urban blocks is a debatable point in urban

resilience because it is directly related to the design of urban transportation network. Fine-grained fabric of the urban zone increases communications, which can enhance urban resilience if an integrated network of urban streets is established. Large-scale urban blocks prevent urban permeability because of less transit paths, which may decrease the resilience. Measurable data of this indicator can be examined by means of analytical tools of GIS.

Connectivity and its measurable variables: this indicator describes the ease of circulation within and around a system, i.e. an integrated urban zone with its transportation network and roads, in terms of morphology and urban spatial analysis. The structure of connections in checkered network of roads determines the contact points between the elements of urban zone and, consequently, the location and intensity of activities (Feliciotti, et al, 2016). This increases the level of accessibility both in the short term and in the short distance, which means an increased access to different urban destinations and the inter-city connections (Marcus & Colding, 2014). The superiority of checkered transportation network over organic network is demonstrated by the results of research on integration of transportation paths using space syntax software (Tarashi & Gharai, 2015). Recent studies show that the proper distance between main street intersections does not exceed 400 meters (Mehaffy, 2015).

Connectivity, which is considered in relation to urban permeability in urban design literature, is agreed upon through smaller urban blocks (according to the conditions of each city and region) because the increased connections enhance the contact points and connectivity between urban elements and facilitate the transit of people and goods (Bentley et al, 2010; Jacobs, 2007). Some researchers believe that both high and low connectivity can be desirable in urban resilience; because of the fact that high connectivity facilitates the dissemination of information and equipment and thus simplifies post-disruption recovery, while low connectivity reduces the spread of disturbance (Chelleri & Olazabal, 2012; Marcus & Colding, 2014). These discussions reveal the complexity of subject. Similar studies that merely address the optimal level of urban blocks can be referred in regard to density and fine-grained fabric (Bentley, et al, 2010), but it still involves further research. The data of this indicator can be measured and examined by the analytical tool of space syntax, which measures the level of integrity, connectivity of roads and spatial depth of transit paths.

Redundancy and its measurable variables: this indicator is a feature in the system that provides a kind of insurance against damage through multiple paths, which have similar functions or work as backup (Ahren, 2011: 342), indicating the abundance of internal components in the system. The difference between redundancy and diversity is that the indicator of diversity includes a variety of urban elements, e.g. various land uses, while the indicator of redundancy includes the multiplicity of a specific type of urban elements, e.g. the multiplicity of main urban roads. Redundancy and abundance of the urban zone components in the system refers to urban density and development that are not discussed in this article and involve another research framework. Multiple backup and strategic urban services can be easily replaced with each other when necessary, allowing the possibility of self-reorganization. Therefore, the promotion of functional redundancy increases the urban resilience (Meerow & Stults, 2016; Marcus & Colding, 2014). Measurable data and variables of redundancy indicator include the multiplicity of alternative transit routes, multiplicity of main urban backup services and enhancement of green spaces and public open areas per capita that increase the urban resilience. Investigations on the appropriate level of redundancy indicator still continue (Chelleri & Olazabal, 2012). But it is evident that a minimum level of support for urban elements is necessary for urban resilience. Another point is that increasing the urban resilience is followed by the enhancement of urban green spaces, which is along with more concentration of

urban elements in form of compact cities, aimed at sustainability (Masnavi, 2011).

Robustness and its measurable variables: this indicator is related to the strength of buildings, roads and physical urban elements and means the ability of a system to resist changes and disturbances without failure or loss of performances; it is also referred to as the sustainability index (Bruneau, et al, 2003; Lu & Stead, 2013). On the one hand, robustness is similar to the traditional notion of engineering resilience with the concept of "bouncing back" and represents a process for maintaining the status quo. On the other hand, it refers to the concept of "bouncing forward", which is derived from the notion of ecological resilience (Meerow & Stults, 2016). In this case, the robustness refers to assessment of resilience and sustainability of the urban zone before the occurrence of an event or disturbance, which makes it possible to predict the resistance of main urban elements using "continuous monitoring" (Sharifi & Yamagata, 2016). Sustainable and resilient urban zones are identified based on the indicators approved by the High Council of Architecture and Urban Development in the Ministry of Roads and Urban Development of Iran, which include three indicators of permeability, sustainability and integration of lands with an area of less than 200 square meters in 50% of the buildings within an urban zone (Ministry of Roads and Urban Development, 2016).

Table 3. Identifications of the four indicators of urban local-spatial resilience according to the spatial organization of the city.
Source: authors, 2018.

Indicators of urban local-spatial resilience	Indicators identifications due to the spatial organization of the city
Diversity	Functional diversity, mixed urban land uses and a variety of open green spaces, spatial diversity that is associated with spatial distribution of urban structural elements for equal public access to basic services throughout the city and reduction of the risk that whole system is affected by a disturbance
Connectivity	Fine-grained fabric and permeability of urban area, integration of main transit paths (checkered road network priority), enhancement of spatial communications in terms of the level of integrity and continuity of roads, and reduction of the spatial depth of transit paths
Redundancy	Main backup and main elements, the number of main urban arteries in order to reach the main services, the abundance and multiplicity of green and urban open spaces, and the number of major urban centers
Robustness	The robustness (sustainability) of roads and buildings and resistance of elements and physical components of the city, such as roads and buildings in the urban area

Table 4. The measurable variables of the four indicators of urban local-spatial resilience. Source: authors, 2018.

References	Resilience Orientation	The measurable variables	Indicators
(wood & Dovey, 2015; Sharifi & Yamagata, 2016; Feliciotti et al, 2016 ; Meerow et al, 2016)	Increase resilience	1) diversity of major axes and functional urban centers, 2) spatial diversity of main urban components, 3) diversity of species and scales of urban green open spaces, and 4) diversity of urban functional zones	**Diversity**
(Suárez et al, 2016; Marcus & Colding, 2014; Feliciotti et al, 2016)	Increase resilience	1) fine-grained fabric and permeability of urban area, 2) integration of main transit paths (checkered road network), 3) enhancement of spatial communications in terms of the level of integrity and continuity of roads, and 4) reduction of the spatial depth of transit paths	**Connectivity**
(Meerow et al, 2016; Marcus & Colding, 2014; Feliciotti et al, 2016)	Increase resilience	1) multiplicity of main routes, 2) multiplicity of main urban support services, and 3) multiplicity of green spots and public spaces	**Redundancy**
(Lu & Stead, 2013; Meerow & Stults, 2016; Sharifi & Yamagata, 2016)	Increase resilience	The robustness (sustainability) of roads and buildings in the urban area, including the width of paths, the structural strength, and the quality of fine-grained fabric	**Robustness**

The contents are summarized in Tables 3 and 4.

Definition of the measurable variables in spatial and temporal scale

The determination of spatial and temporal scale is so important to define the operational indicators and identify measurable data. The urban spatial organization essentially determines the spatial scale of the city and, as seen in the figure, the layer of urban zone derived from the combination of main urban neighborhoods and arteries indicates the proposed scale (Fig. 3). Since the indicators cannot yet be converted into criteria to be accurately represented by numbers, it is recommended to consider the resilience in terms of its orientation, which can be measured over a time interval or at specified time points.

Research Results and discussion

Urban local-spatial resilience may be considered in two sets: 1) the pattern of structure, and 2) the pattern of urban function and dynamics, along with the impact of socio-economic dynamics. The structure and function of urban system is based on spatial organization of the city that includes the components of natural and man-made environment. Natural components such as parks and urban green spaces are studied in terms of the shape and size of green areas within the structural pattern and in terms of the performance of green spaces as urban recreational areas and treatment of urban air pollution within the pattern of urban function and dynamics. Man-made components of the urban spatial organization, such as roads, are reviewed and analyzed in terms of spatial circulations through streets within the structural pattern and in terms of the performance of streets as transit corridors between two urban areas (e.g. highways and main arteries) within the pattern of urban function and dynamics. In this approach, each component of the spatial organization of the city can be investigated and analyzed in the urban system on

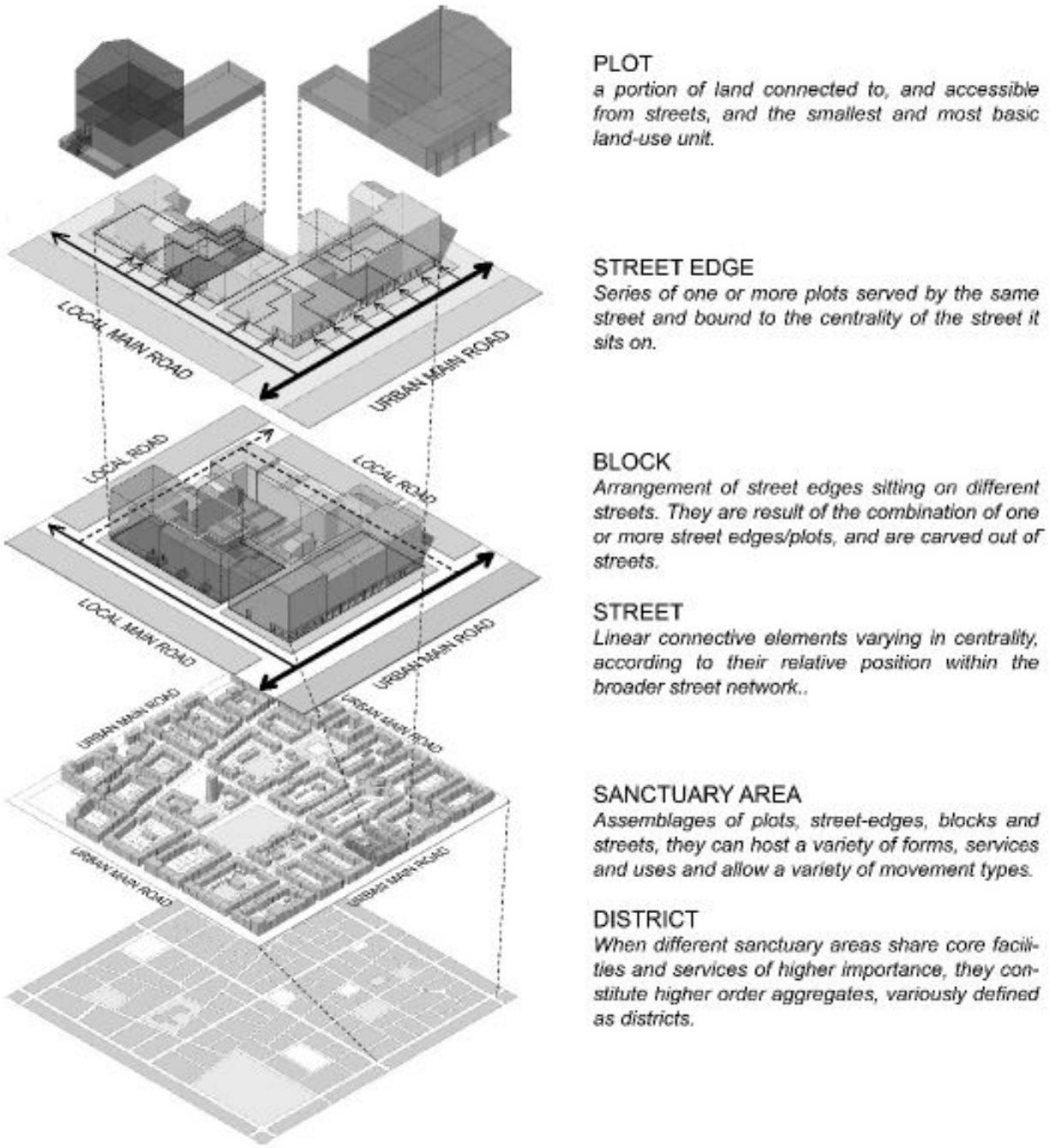

Fig. 3. Hierarchy of morphological scales. Source: Feliciotti, Romice, & Porta, 2016.

specific urban spatial and time scales (Table 5 and 6). The study process was designed to find answers to the research questions and progressed step by step. The relationship between the urban resilience and spatial organization of the city is that resilient cities respond quickly to unexpected situations and continue to function despite difficult conditions. In the long run, a resilient city must be able to return to pre-crisis situations and needs subtle flexible changes and urban development over time. The physical-environmental dimension of urban resilience is related to infrastructure and superstructure facilities

Table 5. The measurable variables of urban local-spatial resilience based on structural pattern. Source: authors, 2018.

Urban local-spatial resilience		Measurable data/variables		Measurement metrics
Structural pattern	Components of the natural environment	Green spaces, forest parks, river valleys, orchards and agricultural lands		Green Spot Size
		Artificial open spaces	Squares	The size and size of public spaces and the number of squares
	Components of the built environment		Streets	The continuity of the main corridors and the axes and the multiplicity of main communication axes
		Blocks built in the form of urban area (urban scale)		Smaller block and more permeability

and environmental features reflected in the urban spatial organization, which include the core function and construction of the city in form of components of the spatial organization. The components of spatial organization of the city are the road network, combination of land plots and urban blocks, open green spaces, land uses and spatial communication between these urban components that are generally analyzed and evaluated in terms of two structural and functional patterns with the aim of prevention before the crisis and improvement after the crisis. It should be noted that although the analysis and evaluation projects of urban spatial organization may involve spending heavy budgets and long time to address the crisis, especially depending on the scale of each city and metropolis, but the added value of security and preparation for dealing with challenges is of great importance. In response to the research question about the role of spatial organization elements of the city in urban local-spatial resilience, the diagram below shows the components of urban spatial organization that influence the orientation of urban local-spatial resilience (Fig. 4). To lead the local-spatial resilience of the city, the resilience of urban system is measured by monitoring the existing status of components within the urban system in order to make necessary decisions on preparation of the urban system for dealing with changes.

Table 6. The measurable variables of urban local-spatial resilience based on functional pattern. Source: authors, 2018.

Urban local-spatial resilience		Measurable data/variables		Measurement metrics
Functional pattern	Components of the natural environment	Green spaces, forest parks, river valleys, orchards and agricultural lands		Functioning of green spaces based on recreational performance and / or urban respiration for healthy weather
		Artificial open spaces	Squares	The diverse function of the squares in the form of plazas or activity hubs
	Components of the built environment		Streets	Performance of the edges of the streets as the axes of action and the role of the street as the focal point
		Blocks built in the form of urban area (urban scale)		The zoning of urban areas

Fig. 4. The diagram of the components of the urban spatial organization that influences the orientation of urban spatial resilience. Source: authors, 2018.

Conclusion

Measurement of urban resilience, especially in terms of its local-spatial dimension, is a new task and in this paper, it was attempted to take a step towards the research on this area by developing the conceptual model of this measurement in relation to spatial organization elements of the city and presenting operational definitions of the indicators and their measurable data. Therefore, comprehensive investigation of the subject requires further research. According to the findings, urban local-spatial resilience was measured by four indicators of diversity, connectivity, redundancy and robustness that were proposed within two structural and functional patterns based on the spatial organization of the city [including roads, urban blocks, green open spaces and functional axes and zones]. Measurable data on indicators of urban local-spatial resilience and their operational definitions were presented by combining the indicators with components of the urban spatial organization, as follows: (A) diversity indicator included an investigation into 1) diversity of major axes and functional urban centers, 2) spatial diversity of main urban components, 3) diversity of species and scales of urban green open spaces, and 4) diversity of urban functional zones; (B) connectivity indicator included an investigation into 1) fine-grained fabric and permeability of urban area, 2) integration of main transit paths (checkered road network), 3) enhancement of spatial communications in terms of the level of integrity and continuity of roads, and 4) reduction of the spatial depth of transit paths; (C) redundancy indicator included an investigation into 1) multiplicity of main routes, 2) multiplicity of main urban support services, and 3) multiplicity of green spots and public spaces; and (D) Robustness indicator referred to the assessment of robustness (sustainability) of roads and buildings in the urban area, including the width of paths, the structural strength, and the quality of the fine-grained fabric. In this research, the spatial scale was an urban scale. The urban scale can be investigated at specific time points in terms of changes in urban structural elements on the urban spatial organization scale described above based on indicators of urban local-spatial resilience. Although this study attempted to explain the relationship of indicators with urban components through operational definition of each indicator, precise elucidation of appropriate level of resilience still requires further research in relation to each urban component, such as roads, urban blocks, functional axes and zones, green open areas, etc.

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