

Exploring the Redundancy Capacity Through a System Dynamics Approach

Marta Bottero, Giulia Datola(✉), and Elena De Angelis

Interuniversity Department of Regional and Urban Studies and Planning, Politecnico di Torino, Turin, Italy
{marta.bottero,giulia.datola,elena.deangelis}@polito.it

Abstract. Current urban agenda is interested in developing urban strategies to enhance urban resilience for cities. This paper examines the concept of urban resilience applied in the context of urban planning with specific attention to which are the capacities that make urban systems resilient. The knowledge and the understanding of these capacities are fundamental to set up suitable strategies. However, only few frameworks consider urban resilience and its capacity within the complexity of urban system. Through an in-depth literature review, this paper aims at providing a methodological framework both to recognize these capacities and analyze which are the main factors that mainly contribute to the achievement of these ability. The paper illustrates the first step of the application of a System Dynamics approach to analyze the redundancy capacity in order to define which are the key variables to enhance this capacity and also to determine which can be the impacts on the urban systems as a whole of the redundancy.

Keywords: Urban resilience · Resilience capacities · System Dynamics Model · Causal loop · Decision-making

1 Introduction

The concept of urban resilience is actually a fundamental objective of the new urban agenda [1–6]. Urban resilience concept is defined as the capacity of the city to adapt, change and absorb in face to a disturbance, within all its dimensions [7]. Global community is interested in enhancing urban resilience for cities, to make them able to face with both natural and man-made hazards [8]. An increasing attention in applying resilience in urban planning is demonstrated by both the growing number of different campaigns [1–3] and by the development of new evaluation frameworks to measure urban resilience [9–16].

Different resilience approaches [17–20] (e.g. engineering, ecological, economical) describe the characteristics, that a system should have to be resilient [21, 22]. These characteristics (i.e. capacities) are namely robustness, stability, flexibility, resourcefulness, coordination capacity, redundancy, diversity, foresight capacity, independence, connectivity and interdependence, collaboration capacity, agility, adaptability, self-organization, creativity and innovation, efficiency, and equity [22, 23]. However, only

© Springer Nature Switzerland AG 2020
O. Gervasi et al. (Eds.): ICCSA 2020, LNCS 12253, pp. 366–378, 2020.
https://doi.org/10.1007/978-3-030-58814-4_26

few frameworks include these capacities in the evaluation. As an example, the "resilience matrix" proposed by Fox-Lent [24] and subsequently implemented by Sharifi [25]. The purpose is constructing a matrix in which urban resilience indicators are putted in relation with the resilience capacities, to aware planners and decision makers of the importance of each ability and characteristic [22, 26–28].

This paper analyses and recognizes the set of the characteristics that can influence urban resilience enhancement (Sect. 2). Based on the existing evaluation methods [11, 26, 29–31], it also proposes a general framework to collect urban resilience indicators within urban resilience capacities. In detail, this paper applies this framework to recognize those urban resilience indicators related to the redundancy. Moreover, the application of System Dynamics approach [32–35] has been proposed to analyze the mutual influences between redundancy and its referred criteria, to analyze this capacity within the complexity of urban systems [32]. The results is a causal loop in which mutual influences have been identified, underling also which can be the effects of the redundancy capacity on the city as a system [35].

2 Urban Resilience Qualities

As above mentioned, the main characteristics that make a city resilient have to be determined to properly define and evaluate strategies to enhance urban resilience. This section illustrates and describes those capacities that urban systems should have to maintain or enhance their resilience. This list is the result of a literature review about resilience characteristics, described both in different resilience approaches [22, 36] and in several urban resilience campaigns [13].

Figure 1 illustrates the capacities of resilient systems, recognised in different approaches, such as ecology, sustainability and climate change [22].

In details, this dissertation is focused on those capacities referred to urban resilience, which can be summarised as follow:

- Reflexive. Reflective systems accept changings in continuous. To being reflexive, systems need mechanisms able to evolve continuously. The objective is be able to modify standards or norms in according to emerging evidences. As a result, people and institutions analyze and systematically learn from their past experiences, to base future decision-making [13];
- Robust. Robust systems include well-conceived, constructed and managed physical assets. The target is being able to withstand the impacts of hazard events without significant damages. In details, robust design foresees potential failures in systems [13];
- Redundant. Redundancy includes also diversity, or rather the presence of different ways to achieve needs. Redundancy can be explained with the repetition of the same elements, in order to guarantee the functionality of the systems in case of emergency events [13];
- Flexible. Flexibility is the capacity to react to unexpected events [37]. The lack of flexibility characterizes often the disaster management systems. In fact, flexibility implies the ability of the systems to change, evolve and adapt in response to evolving

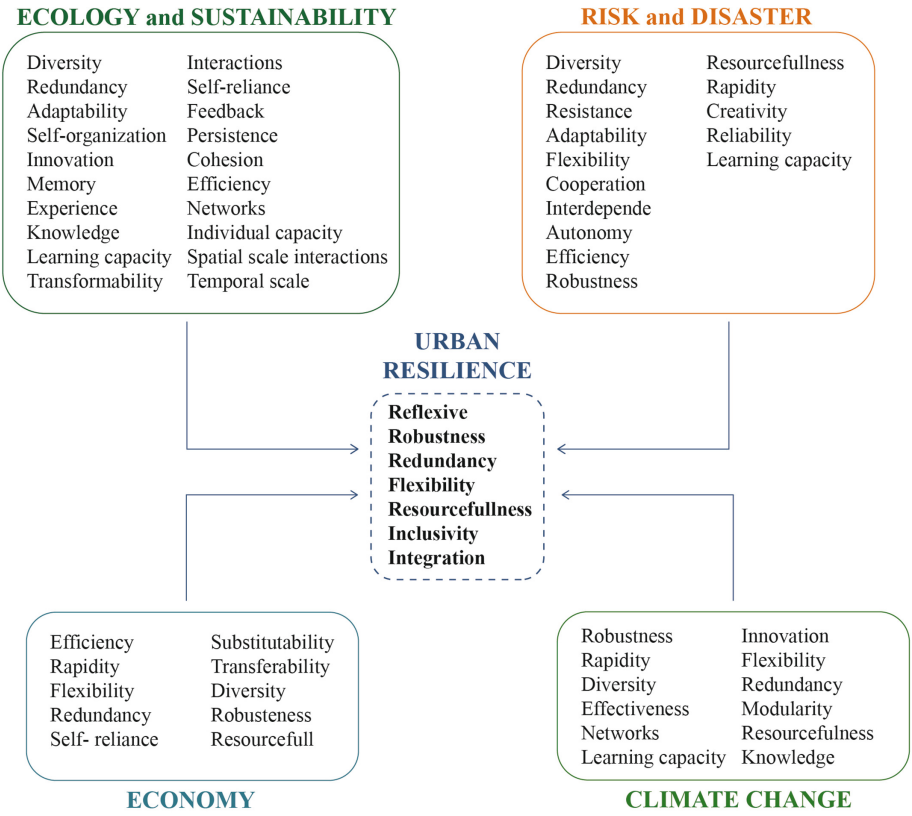

Fig. 1. Approach to collect urban resilience capacities (elaboration from Galderisi 2010)

situations [38]. Furthermore, it may favor decentralization and modular approaches for the management of infrastructure and ecosystem management [13];

- Resourceful. This capacity includes the ability of the system to anticipate future conditions and in setting priorities. It also implicates that both citizens and institution should be able to achieve their goals or meet their needs during a shock or when under stress [13];
- Inclusive. It is referred to the consultation and the engagement of communities, in order to reduce also the social vulnerability [13];
- Integrated. Integration and alignment between city systems promote consistency in decision-making and ensure that all investments are mutually supportive to a common outcome. Integration is evident within and between resilient systems, and across different scales of their operation. Exchange of information between systems enables them to function collectively and respond rapidly through shorter feedback loops through the city [13].

3 Redundancy Indicators

As mentioned in the first section, this paper analyses the capacity of redundancy. This capacity is related to the ability of the urban system to keep a satisfactory level of performance following an unexpected event. It is related to the presence of different elements with the same function, ensuring the continuity in case some elements fails [39, 40] and it is fundamental to ensure the continuity of urban performances. Table 1 lists a multi-dimensional set of urban resilience indicators, which are referred to redundancy. They are the result of an in-depth literature review about urban resilience indicators [16, 25, 29–31]. In detail, the literature review has been carried out through the support of the Scopus platform, using the keywords "urban resilience indicators", "resilience capacities" and "redundancy capacity". Moreover, different resilience assessment approaches [13, 41, 42] and several case studies have been analyzed [43, 44], to better understand how these indicators can be applied in the evaluation.

Table 1. Urban resilience indicators referred to redundancy capacity

Dimension	Criteria	Description	Unit	Capacity	Impact	Source
Social	Access to internet services	Percentage or number of household with access to broadband internet services	[num./%]	Robust, Redundant, Inclusive	+	Cutter et al. 2014
	Accessibility to public transport	Number of public transportation stop/1000 inhabitants.	[num.]	Inclusive, Redundant	+	Cutter et al. 2014
	Quantity of service facility	Number of service facility in the municipality	[num.]	Inclusive, redundant	+	Adapted from Cutter et al. 2014
	Number of hospital	Number of hospital per 10.000 person	[num.]	Inclusive, redundant	+	Cutter et al. 2014
	Public space	Surface of public space, open for public use	[hectares/m^2]	Redundant		Adapted from UNISDR 2015
	Accessibility to food distribution	Percentage of population which can access to food serves	[%]	Inclusive, Redundant	+	Adapted from Mercycrop 2016

(*continued*)

Table 1. (*continued*)

Dimension	Criteria	Description	Unit	Capacity	Impact	Source
Environment	Water supply	Number of different supply sources providing at least 5% of water supply capacity	[num.]	Redundant, Flexible	+	OECD, 2018; Cutter et al. 2014
	Diversity renewable energy	Number of different source of renewable energy	[num.]	Redundant, Flexible	+	Feldmeyer, 2019; Eurostat 2017
Economic	Diversification of economic business	Number of people or percentage of population not employed in the first economic sector	[num./%]	Redundant, Resourceful	+	Adapted from Cutter et al. 2010
Infrastructure	Emergency points/recovery points	Number of emergency point located in the municipal territory per 10.000 population	[num.]	Redundant	+	Feldemeyer 2019
	Arterial roads	Kilometres of main streets	[km linear]	Redundant	+	Cutter et al. 2014
	Multifunctional spaces	Surface or number of space with multifunctional characteristics that can be adapted	[hectares/m^2]	Redundant	+	Cutter et al. 2014
Governance	Risk assessment report	Presence or not of risk assessment report in urban development policy	[0–1]	Redundant	+	Arup 2015
	Climate action plan	Presence or not of climate action plan in urban development policy	[0–1]	Redundant	+	Cutter et al. 2014

For this reason, this paper provides a method to collect and describe these criteria considering: (1) dimension, (2) description, (3) unit, (4) capacity, (5) impact (Positive "+" or negative "−"), and (6) source, in order to combine and integrate the different information provided in literature [13, 16, 25, 29–31, 41]. The objective is underling the capacities to which they are referred to, putting in evidence which can be their possible influence.

4 System Dynamics Approach

System Dynamics Model are both computer-aided and theoretical approach applied to analyze dynamic and complex systems by the identification of the mutual interdependences between variables [46]. SDMs are based on the System Dynamics approach. The methodology of the System Dynamics (SD) has been introduced by Forrester at the end of '50s to analyze and improve the understanding of complex systems [33–35]. SD is based on feedback concepts to handle non-linearity and multi-loop that characterize complex systems. In fact, it is considered as a suitable tool to examine and illustrate the functioning of complex systems through the identification of the interdependent relationships between their variables [47]. Furthermore, it can be applied to model and simulate the behavior of complex dynamic systems to understand and analyze their dynamics and design development policies [35, 44–46]. System dynamics is a tool for understanding the change of a dynamic system over time. This approach can help in understanding the impacts of various factors on defined objectives in a system and provide useful information for decision makers [29, 35, 46, 48–52].

In details, there are six steps through analyze and describe complex systems through the SD approach [35, 43]. These phases are:

1. Identify the problem;
2. Develop a dynamics hypothesis, explaining the cause of the problem;
3. Create a basic structure of a causal graph;
4. Argument the causal graph with more information;
5. Convert the augmented causal graph into a system dynamics flow graph;
6. Translate a system dynamics flow into SD models

4.1 Causal Loop

Defined the variables of the system, the following step is developing the causal loop diagram, identifying the relationships and feedback loops between variables [42, 43]. The causal loop diagram illustrates the feedback structure of the system. It represents the reference mode that causes the dynamic behavior of the system [34]. It is also a tool to represent the relationships between variables. In detail, the relationships between variables can be either positive or negative. A positive relationship means that the variables will change in accordance to each other. Instead, the negative relationship implicates that the variables will change in opposite way.

The process to structure the causal loop diagram can be described within these phases:

- Define the problem and the objective;

- Identify the most important elements of the systems;
- Identify the secondary important elements of the systems;
- Identify the tertiary important elements of the systems;
- Define the cause-effect relationships.

As an example, Fig. 2 illustrates the causal loop referred to the population. Two different loops are identified, loop "R+" and "B−". Loop "R+" is a positive loop. It means that the population will grow with births, and the number of birth will increase with the population augment. It is a reinforcing loop, or rather the variable will change in the same direction over time [34]. Loop "B−" means that the number of deaths will grow with the population and the population will decrease as the death increasing.

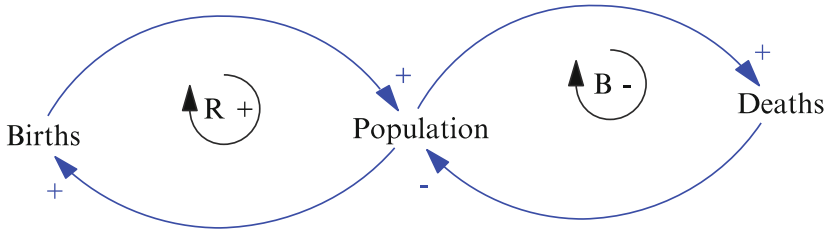

Fig. 2. Causal loop diagram of population (Bala et al. 2017)

5 Analyzing Redundancy Through System Dynamics Approach

As mentioned in the first section, cities are complex, adaptive and dynamic systems [35]. It implies that their multi-dimensional components are influencing each other, determining the evolution of cities over time [47, 48]. It is fundamental to provide a tool able to consider how different elements can influence each other and how factors can impact on a defined objective, in accordance to urban resilience enhancement [10]. This paper proposes the employment of the causal loop diagram to determine both how urban resilience indicators can influence the redundancy, and how redundancy should affect these variables. This choice has been also made in accordance to the fact that resilience can be interpreted as the result of different capacities that are mutually interrelated [53].

The challenge is providing a framework able to manage this complexity, to support decision makers in the identification of the key variables and their possible impacts on the city as whole, within urban resilience enhancement. Figure 3 illustrates the causal loop developed to analyze the redundancy. This causal loop has been developed following the phases mentioned in the previous section (Sect. 4.1). Firstly, the objective has been clarified, or rather "analyze how the variables can influence the redundancy and how the employment of the redundancy concept in urban development strategy could affect city as a whole". Secondly, the most important elements of the examined issue have been determined (Table 1). For this phase, all indicators listed in Table 1 have been identified as the most important elements of the system. Thirdly, the causal loop between the most important variables have been designed. The mainly loops identified among

redundancy and variables are: (1) Infrastructure for internet service "A"; (2) Arterial roads "B"; Emergency points "C", Number of hospital "D". Secondly, also some loops between variables themselves have been recognized: loop "E" among "infrastructure for internet services" and "quantity of services"; "F" among "renewable energy" and "diversity in renewable energy" and "G" between "diversification of economic business" and "economic development". Furthermore, through this causal loop diagram, also some secondary variables of the city have been identified, namely: (1) vulnerable people, (2) road demand, (3) road improvement rate, (4) urban area, (5) soil consumption, (6) renewable energy, (7) offer of public transport. These variables are not listed in Table 1, because they do not influence redundancy in directly way. However, they are connected to the primary variable (Table 1) and they can influence the redundancy through both a reinforcing loop or by a negative influence.

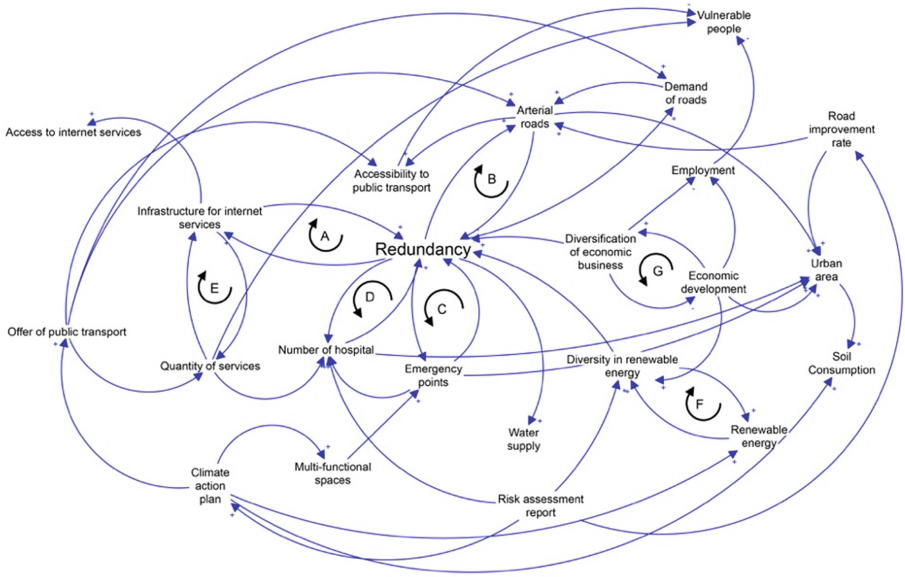

Fig. 3. Causal loop of redundancy

6 Discussion

The causal loop processing (Fig. 3) has been useful to determine:

- The loops between redundancy and indicators;
- The mutual relationships and loops among the considered indicators

Through the development of the causal loop, it was possible to reason about how the considered indicators (Table 1) can influence redundancy and how redundancy can influence these variables, within the objective of enhancing urban resilience. As illustrated

in Fig. 3, different loops have been identified. Positive loops, namely "A", "B", "C" and "D" have been identified among redundancy and four indicators, or rather (1) infrastructure for internet services, (2) arterial roads, (3) emergency points and (4) number of hospitals. As an example, loop "A" means that the implementation of the redundancy in urban development strategy will increase the number of the infrastructure for internet services and the growing in the infrastructure for internet services will improve the redundancy capacity. Equally, for loop "B", "C" and "D", the redundancy implementation will increase the number of hospitals, number of arterial roads, and the number of emergency points and the growing of these elements will improve the redundancy capacity. Thus, these causal loops are reinforcing loops [34], that means that the variables will change in the same direction over time.

As above mentioned, also the secondary variables have been identified during the causal loop drawing. Consequently, three loops among the primary and secondary variables have been recognized, or rather loop "E", "F" and "G".

As an example, the loop "G" can be discussed. This loop is between "economic development" and "diversification of economic business". It means that the economic development will increase with the encouragement of the diversification of the economic business and the diversification of the economic business will grow with the improvement of the economic development. Furthermore, also the loop "F" is very interesting within the redundancy analysis. It is a positive and reinforcing loop between "renewable energy production" and the "diversity in renewable energy". It means that the "renewable energy production" will increase with the improvement of the "diversity in renewable energy" and the "diversity in renewable energy" will grow through the increase of "renewable energy production". As the same time, also the loop "G" is a positive loop. It determines that the increasing of the "quantity of services" will implement the "infrastructure for internet services" and the growing in the "number of the infrastructure for internet services" will increase the "quantity of services".

Moreover, through the identification of the secondary variables, other important relationships have been identified. As an example, it has been recognised that the improvement of the (1) accessibility to public transport, (2) the increasing of the quantity of services and the (3) possible improvement in employment, related to the enhancement of the redundancy, can reduce the quantity of the vulnerable people [54]. At the same time, it is also possible to underline that the redundancy enhancement should have negative impacts on the environmental dimension. In fact, the growing of (1) main roads, (2) number of hospitals and (3) emergency points could increase the surface of the urban area and consequently the soil consumption rate. These consequences are also in accordance to the issues underlined by Walker related to the conflicts between resilience and sustainability [55]. In this sense, the causal loop diagram (Fig. 3) has been fundamental to underline how the capacity of the redundancy can have both positive and negative impacts on the urban system, as a whole.

7 Conclusions and Future Developments

The paper recognizes the capacities that make a city resilient (Sect. 2) [23] and provides a multi-dimensional set of urban resilience indicators referred to the redundancy capacity

(Table 1). Moreover, it illustrates a preliminary application of SD approach to analyze the relationships between the redundancy and its variables, through the development of the causal loop diagram (Fig. 3). The illustrated application can be considered as preliminary step in the SD employment to analyze urban resilience within its capacities. It has been useful to underline its suitability in managing complexity and in identifying the probable impacts of different factors on the same objective [34]. Considering the recognized potentialities, the future development of this research should be organized with a sequential organization. Firstly, the causal loop (Fig. 3) has to be translated into the stock and flow diagram. It is necessary to evaluate the consistency of the redundancy impacts on the urban system over time [56]. Secondly, a System Dynamics Model that embrace all urban resilience capacities with their indicators will be processed. The challenge is providing a general evaluation framework, that is able to analyze urban resilience within its capacities [57], managing cities as complex and adaptive systems [35]. The final objective is proposing an evaluation tool to assess urban development strategies [46, 54, 55], considering their probable impacts on urban system over time. Thus, this research can support the definition of actions and policies for urban resilience enhancement, predicting their probable effects [62]. Furthermore, this general framework should be integrated with the multi-criteria analysis [58, 60, 61], to consider the specific characteristic of context both in the evaluation and in setting developing strategies [57–59].

References

1. Mart, C., et al.: A Midterm Monitoring and Evaluation Report of 100 Resilient Cities and the participation of (2018)
2. Event, N.: Making Cities Resilient 2030 Introduction & Background. 2030, 1–19
3. Helena, M.V., Dilanthi, A., Richard, H.: Making Cities Resilient: from awareness to implementation. Int. J. Disaster Resil. Built Environ. **4**, 5–8 (2013). https://doi.org/10.1108/17595901311299035
4. UNISDR (United Nations Office for Disaster Risk Reduction): Sendai Framework Data Readiness Review 2017, Disaster-related Data for Sustainable Development (2017)
5. UNISDR: Hyogo Framework for Action 2005–2015. In: United Nations International Strategy for Disaster Reduc (2005). https://doi.org/10.1017/CBO9781107415324.004
6. Masnavi, M.R., Gharai, F., Hajibandeh, M.: Exploring urban resilience thinking for its application in urban planning: a review of literature. Int. J. Environ. Sci. Technol. **16**(1), 567–582 (2018). https://doi.org/10.1007/s13762-018-1860-2
7. Meerow, S., Newell, J.P., Stults, M.: Defining urban resilience: a review (2016). https://doi.org/10.1016/j.landurbplan.2015.11.011
8. World Economic Forum: The Global Risks Report 2018 13th Edition (2013). ISBN 978-1-944835-15-6
9. Tremml-Werner, B.: The Comparative Framework. Spain, China and Japan in Manila, 1571-1644, 43–90 (2018). https://doi.org/10.1515/9789048526819-003
10. Ilmola, L.: Approaches to measurement of urban resilience. In: Yamagata, Y., Maruyama, H. (eds.) Urban Resilience. ASTSA, pp. 207–237. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-39812-9_11
11. Moghadas, M., Asadzadeh, A., Vafeidis, A., Fekete, A., Kötter, T.: A multi-criteria approach for assessing urban flood resilience in Tehran. Iran. Int. J. Disaster Risk Reduct. **35**, 101069 (2019). https://doi.org/10.1016/j.ijdrr.2019.101069

12. Quinlan, A.E., Berbés-Blázquez, M., Haider, L.J., Peterson, G.D.: Measuring and assessing resilience: broadening understanding through multiple disciplinary perspectives. J. Appl. Ecol. **53**, 677–687 (2016). https://doi.org/10.1111/1365-2664.12550
13. Da Silva, J., Moench, M.: City Resilience Framework. Arup (2014). http://www.seachangecop.org/files/documents/URF_Bo
14. Resilience, C.: City Resilience Index
15. Sellberg, M.M., Wilkinson, C., Peterson, G.D.: Resilience assessment: a useful approach to navigate urban sustainability. Ecol. Soc. **20**, 43 (2015)
16. Sharifi, A.: A critical review of selected tools for assessing community resilience. Ecol. Indic. (2016). https://doi.org/10.1016/j.ecolind.2016.05.023
17. Meerow, S., Newell, J.: Resilience and complexity: a bibliometric review and prospects for industrial ecology. J. Ind. Ecol. **19** (2015). https://doi.org/10.1111/jiec.12252
18. Adger, W.: Social and ecological resilience: are they related? Prog. Hum. Geogr. **24**, 347–364 (2000). https://doi.org/10.1191/030913200701540465
19. Kantsler, V., Steinberg, V.: Orientation and dynamics of a vesicle in tank-treading motion in shear flow. Phys. Rev. Lett. **95** (2005). https://doi.org/10.1103/PhysRevLett.95.258101
20. Rose, A.: Economic resilience to natural and man-made disasters: multidisciplinary origins and contextual dimensions. Environ. Hazards **7**, 383–398 (2007). https://doi.org/10.1016/j.envhaz.2007.10.001
21. Lazarević, E.V., Kekovi, Z., Antoni, B.: Insearch of the principles of resilient urban design: implementability of the principles in the case of the cities in Serbia. Enery Build. **158**, 1130–1138 (2018). https://doi.org/10.1016/j.enbuild.2017.11.005
22. Galderisi, A.: Urban resilience: a framework for empowering cities in face of heterogeneous risk factors. A|Z ITU J. Faculty Architect. **11**, 36–58 (2014)
23. Cutter, S.L.: The landscape of disaster resilience indicators in the USA. Nat. Hazards **80**(2), 741–758 (2015). https://doi.org/10.1007/s11069-015-1993-2
24. Fox-Lent, C., Bates, M.E., Linkov, I.: A matrix approach to community resilience assessment: an illustrative case at Rockaway Peninsula. Environ. Syst. Decis. **35**(2), 209–218 (2015). https://doi.org/10.1007/s10669-015-9555-4
25. Sharifi, A., Yamagata, Y.: Urban resilience assessment: multiple dimensions, criteria, and indicators. In: Yamagata, Y., Maruyama, H. (eds.) Urban Resilience. ASTSA, pp. 259–276. Springer, Cham (2016). https://doi.org/10.1007/978-3-319-39812-9_13
26. Sharifi, A., Yamagata, Y.: Principles and criteria for assessing urban energy resilience: a literature review (2016). https://doi.org/10.1016/j.rser.2016.03.028
27. Sharifi, A., Yamagata, Y.: Resilient urban planning: major principles and criteria. Energy Procedia (2014). https://doi.org/10.1016/j.egypro.2014.12.154
28. Cutter, S.L., et al.: A place-based model for understanding community resilience to natural disasters. Glob. Environ. Chang. (2008). https://doi.org/10.1016/j.gloenvcha.2008.07.013
29. Figueiredo, L., Honiden, T., Schumann, A.: OECD Regional Development Working Papers 2018/02 Indicators for Resilient Cities (2018)
30. Cutter, S.L., Burton, C.G., Emrich, C.T.: Disaster resilience indicators for benchmarking baseline conditions. J. Homel. Secur. Emerg. Manag. (2010). https://doi.org/10.2202/1547-7355.1732
31. Feldmeyer, D., et al.: Indicators for monitoring urban climate change resilience and adaptation. Sustainability **11**(10), 2931 (2019)
32. Forrester, J.W.: Principles of Systems. Productivity Press, Portland (1990)
33. Forrester, J.W.: Industrial Dynamics. MIT Press, Cambridge (1961)
34. Bala, B.K., Arshad, F.M., Noh, K.M.: Systems thinking: system dynamics. In: System Dynamics: Modelling and Simulation. pp. 15–35. Springer, Singapore (2017). https://doi.org/10.1007/978-981-10-2045-2_2

35. Batty, M.: Cities as Complex Systems: Scaling, Interaction, Networks, Dynamics and Urban Morphologies. Work. Pap. CASA Work. Pap. (131). Cent. Adv. Spat. Anal. (UCL), London (2012). https://doi.org/10.1007/978-0-387-30440-3_69
36. Leichenko, R.: Climate change and urban resilience, 164–168 (2011). https://doi.org/10.1016/j.cosust.2010.12.014
37. Godschalk, D.: Urban Hazard Mitigation: Creating Resilient Cities. Nat. Hazards Rev. **4** (2003). https://doi.org/10.1061/(ASCE)1527-6988(2003)4:3(136)
38. Gibson, C.A., Tarrant, M.: A "conceptual models" approach to organisational resilience: gibson and tarrant discuss the range of inter-dependant factors needed to manage organisational resilience. Aust. J. Emerg. Manag. **25**, 6–12 (2010)
39. Chuvarayan, A., Martel, I., Peterson, C.: A Strategic Approach for Sustainability and Resilience Planning within Municipalities (2006)
40. Bruneau, M., et al.: A framework to quantitatively assess and enhance the seismic resilience of communities. Earthq. Spectra **19** (2003). https://doi.org/10.1193/1.1623497
41. Fu, X., Wang, X.: Developing an integrative urban resilience capacity index for plan making. Environ. Syst. Decis. **38**(3), 367–378 (2018). https://doi.org/10.1007/s10669-018-9693-6
42. O'Connell, D., Walker, B., Abel, N., Grigg, N.: The Resilience, Adaptation and Transformation Assessment Framework: From Theory to Application (2015). https://doi.org/10.13140/RG.2.1.4301.4564
43. Suárez, M., Gómez-Baggethun, E., Benayas, J., Tilbury, D.: Towards an urban resilience index: a case study in 50 Spanish cities. Sustain. (2016). https://doi.org/10.3390/su8080774
44. Tabibian, M., Rezapour, M.: Assessment of urban resilience; a case study of Region 8 of Tehran city, Iran. Sci. Iran. **23**, 1699–1707 (2016). https://doi.org/10.24200/sci.2016.2240
45. UNISDR: Making Cities Resilient Report 2012 (2012). https://doi.org/10.1177/0956247814522154
46. Rouwette, E., Vennix, J.: System dynamics and organizational interventions. Syst. Res. Behav. Sci. **23**, 451–466 (2006). https://doi.org/10.1002/sres.772
47. Sterman, J.: Business Dynamics, System Thinking and Modeling for a Complex World 19 (2000). http://lst-iiep.iiep-unesco.org/cgi-bin/wwwi32.exe/[in=epidoc1.in]/?t2000=013598/(100)
48. Park, M., Kim, Y., Lee, H., Han, S., Hwang, S., Choi, M.: Modeling the dynamics of urban development project: focusing on self-sufficient city development. Math. Comput. Model. **57**, 2082–2093 (2013). https://doi.org/10.1016/j.mcm.2011.05.058
49. Wu, D., Ning, S.: Dynamic assessment of urban economy-environment-energy system using system dynamics model: a case study in Beijing. Environ. Res. **164**, 70–84 (2018). https://doi.org/10.1016/j.envres.2018.01.029
50. Tan, Y., Jiao, L., Shuai, C., Shen, L.: A system dynamics model for simulating urban sustainability performance: a China case study. J. Clean. Prod. **199**, 1107–1115 (2018). https://doi.org/10.1016/j.jclepro.2018.07.154
51. Forrester, J.W.: Urban Dynamics. MIT Press, Cambridge (1979)
52. Alfeld, L.E., Graham, A.K.: Introduction to Urban Dynamics. Wright-Allen Press, Cambridge (1976)
53. Norris, F.H., Stevens, S.P., Pfefferbaum, B., Wyche, K.F., Pfefferbaum, R.L.: Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. Am. J. Commun. Psychol. **41**, 127–150 (2008). https://doi.org/10.1007/s10464-007-9156-6
54. Joakim, E., et al.: Using system dynamics to model social vulnerability and resilience to coastal hazards. Int. J. Emerg. Manag. **12**, 366 (2016). https://doi.org/10.1504/IJEM.2016.079846
55. Walker, B., Salt, D., Reid, W.: Resilience Thinking: Sustaining Ecosystems and People in A Changing World. Bibliovault OAI Repos. Univ. Chicago Press (2006)

56. Datola, G., Bottero, M., De Angelis, E.: How urban resilience can change cities: a system dynamics model approach. In: Misra, S., et al. (eds.) ICCSA 2019. LNCS, vol. 11622, pp. 108–122. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-24305-0_9
57. Kuznecova, T., Romagnoli, F.: System Dynamics approach within the context of city resilience and urban metabolism (2014). https://doi.org/10.3846/enviro.2014.125
58. Bottero, M., Comino, E., Dell'Anna, F., Dominici, L., Rosso, M.: Strategic assessment and economic evaluation: the case study of Yanzhou Island (China). Sustainability (2019). https://doi.org/10.3390/su11041076
59. Assumma, V., Bottero, M., Datola, G., De Angelis, E., Monaco, R.: Dynamic models for exploring the resilience in territorial scenarios. Sustainabilty (2020). https://doi.org/10.3390/su12010003
60. Roy, B., Vincke, P.: Multicriteria analysis: survey and new directions. Eur. J. Oper. Res. **8**, 207–218 (1981)
61. Figueira, J., Greco, S., Ehrgott, M.: Multiple criteria decision analysis, state of the art surveys. Mult. Criteria Decis. Anal. State Art Surv. **78** (2005). https://doi.org/10.1007/b100605
62. Bottero, M., Caprioli, C., Cotella, G., Santangelo, M.: Sustainable cities: A reflection on potentialities and limits based on existing eco-districts in Europe. Sustainability (2019). https://doi.org/10.3390/su11205794