Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Environmental Sustainability

Urban resilience and green infrastructure systems: towards a multidimensional evaluation

Adriana A Zuniga-Teran, Andrea K Gerlak, Brian Mayer, Tom P Evans and Kevin E Lansey

Multifunctional and connected green infrastructure (GI) systems have been linked to urban resilience. Although there have been significant scholarly efforts to assess resilience and to evaluate the benefits of GI, it remains unclear the degree in which GI efforts enhance resilience. Following theoretical frameworks that study coupled infrastructure systems, this paper explores the state of the art on the contribution of GI to urban resilience from multiple dimensions: (1) policy - that promotes the adoption of GI, (2) performance - assessment of GI impacts on water infrastructure systems resilience, (3) connectivity - evaluation of human and wildlife movement through GI, and (4) social - community cohesion as a result of GI efforts. We argue that beyond their individual contributions to supporting urban resilience, the interactions across the various dimensions are key to enhancing resilience. Ultimately, participatory processes are needed to assess resilience originating from GI systems and avoid injustice.

Address
University of Arizona, United States

Corresponding author:
Zuniga-Teran, Adriana A (aazuniga@email.arizona.edu)

Current Opinion in Environmental Sustainability 2020, **44**:42–47

This review comes from a themed issue on **Resilience and complexity: frameworks and models to capture social-ecological interactions**

Edited by **Christopher A Scott** and **François-Michel Le Tourneau**

Received: 23 September 2019; Accepted: 18 May 2020

https://doi.org/10.1016/j.cosust.2020.05.001

Introduction

As a result of urbanization processes and climate change impacts, unprecedented environmental and social challenges have emerged in cities that threaten the functioning of critical infrastructure and add pressure to local institutions [1]. These impacts intersect with globalization and neo-liberalization processes that exacerbate inequalities, enhance vulnerability, and weaken social and ecological resilience [1,2••]. Multifunctional and connected green infrastructure (GI) systems have been identified as a promising approach to enhance resilience in cities. We understand GI as vegetated spaces in cities that are designed to function as decentralized stormwater management infrastructure systems (runoff infiltration that reduce flooding) and other environmental benefits, as well as recreational spaces for urban residents (e.g. parks, sport fields, golf courses, school fields). Although there have been multiple studies that aim to assess urban resilience [3–6], as well as significant efforts that aim to evaluate the benefits of GI [7–10], it remains unclear the degree in which GI efforts enhance urban resilience. In this essay, we address this gap by exploring the state of the art on the contribution of GI to urban resilience from multiple dimensions.

Urban resilience is a term used to ‘frame how actors and infrastructures across all scales (individual, household, community, organization, region) contribute to the capacity to survive, respond, recover, adapt and evolve in reaction to chronic and acute stresses and events that disrupt everyday systems and practices’ (p.1) [11]. Zhang and Li [12] highlight the need to disentangle urban resilience from urban sustainability; and Elmqvist *et al.* [13] identify the importance of *urban transformation* given the urgent need for cities to address and mitigate future social and environmental challenges.

To function effectively, cities currently depend on robust grey infrastructure systems – a connected network of infrastructure that supports the provision of shelter, water, waste, energy, and transportation services. Critical infrastructure determines the level of vulnerability of the city, as the structures and facilities that allow the infrastructure to function can either lessen vulnerability or enhance it [14]. This way, to be resilient and address vulnerability issues, urban planning needs to be flexible and adaptive, allowing the exploration of innovative and transdisciplinary practices [15]. Embedding resilience in all its forms – institutional, climate, economic, and ecological – in critical infrastructure systems, while strengthening social cohesion becomes a priority [16•].

Research has shown that traditional grey infrastructure systems are not enough to withstand the impacts of globalization, urbanization, and climate change, and that nature-based solutions — such as GI systems — are needed to complement and support the functioning of grey infrastructure systems in green-grey-blue hybrid systems [1,11,17]. GI also contributes to the conservation of biodiversity as it provides habitat for species; relieves pressure on the environment from urbanization and land use change [1,9,18]; improves the quality of life by providing recreational opportunities [9,19]; and supports social networks that increase social cohesion [20]. GI can be defined as 'the creative combination of natural and artificial (blue and green as well as grey) structures intended to achieve specific resilience goals (e.g., flood management, public health, etc.) with broad public support and attention to the principle of appropriate technology' (p.1) [17]. GI is being incorporated into resilience planning in many cities around the world [21].

Assessing the performance of GI with regards to urban resilience is needed, yet complicated to achieve, as there have been important assessment efforts on both fronts, but not integrated. On the one hand, measuring urban resilience is a multidimensional endeavor. According to Meerow [1], there is disagreement among scholars on the assessment of urban resilience, but factors that are widely cited in the literature include diversity, flexibility, redundancy, and inclusiveness. In addition, Leichenko [16•] identifies two more factors of resilient cities: adaptive governance (which is related to flexibility), and innovation. But none of these factors focus on GI in particular. On the other hand, measuring the benefits of GI is also complicated. Pakzad and Osmond [9] explore the assessment GI performance as it relates to ecological, health, socio-cultural, and economic outcomes. But, again, this assessment is not related directly to urban resilience.

In addition to integrating assessment efforts, it is necessary to consider key principles for an equitable, just, and effective implementation of GI, which include *connectivity* and *multifunctionality* [22,23]. Artmann *et al.* [24] includes multifunctionality as one category of indicators to measure a smart green city. GI has the potential to function as a decentralized stormwater management infrastructure, particularly if it is connected to a larger network of GI; and simultaneously, GI can provide recreational opportunities to urban residents whenever flood control and other disaster management functions are not needed [1,20,23]. However, GI's multifunctionality is an underlying difficulty in evaluation [11,17].

Another key aspect to consider in the assessment of resilience from GI systems is the economy. Economic resilience can be related to greening behavior, particularly during disaster recovery situations, where the planting of trees and other plants plays a role not only the social and ecological recovery, but also in the economic recovery of the city [20]. Ironically, mainstreaming GI in built environment professions requires considerable funding and comprehensive planning [1,21,25]. In addition, there are significant challenges in implementing resilience thinking to change the trajectories of urban planning initiatives [26], and there are pitfalls in placing too much confidence in overly simplistic approaches [27].

Because GI is one type of critical infrastructure, a useful approach to study the contributions of GI to urban resilience may be the notion of *coupled infrastructure systems* or CIS. The term CIS proposes that functional infrastructures are the building blocks of the interactions between people and their environment, with feedback effects derived from such interactions [28•]. This way, and analogous to social-ecological systems, cities can be considered CIS because of the prominent role that infrastructures — both hard (pipes, roads, bridges, GI) and soft (policy, social networks, knowledge) — play in the interactions of urban systems [14,28•]. In this study, we build on this line of research to explore the assessment of urban resilience from GI systems, considering GI as one building block of CIS that contributes to multiple outcomes that affect urban systems.

Key dimensions of urban resilience from green infrastructure systems

In this study, we aim to assess the different types of urban resilience (institutional, climate, economic, and ecological) from a connected network of multifunctional GI systems. To do this, we propose four dimensions that follow Anderies *et al.'s* [28•] key components of CIS: (1) soft infrastructure, which we refer to as *policy*; (2) built infrastructure (or hard), which we refer to as *performance*; (3) natural, which we refer to as *connectivity*, and (4) *social*. The CIS framework includes one more dimension - human knowledge, which corresponds to our effort to assess urban resilience from GI systems (Table 1). Here we examine how these four dimensions of CIS have been used to provide insight into the resilience of urban areas in the context of GI.

Table 1

Overview of the four dimensions to assess urban resilience from GI systems

Dimension	Type of resilience	Description
Policy	Institutional	Types of regulations, policies, initiatives, and programs that promote the implementation of GI in cities
Performance	Climate, economic and ecological	Metrics used to assess the impacts of GI on the reduction of floods and the resilience of water infrastructure systems
Connectivity	Climate, economic and ecological	Methods used to evaluate the connectivity of GI systems
Social	Climate and economic	Ways in which social resilience related to GI can be assessed in cities

Policy

Cities can support GI through a diversity of policy approaches [29]. Many cities around the world have been integrating GI projects with their traditional grey infrastructure stormwater management efforts to support flood risk management and build climate resilience [e.g. Refs. 17,30]. Some cities use regulation to promote widespread GI adoption through mandates that new buildings include green roofs, or new developments include greenspace [31]. Rainwater harvesting systems have been included in building codes in some cities to promote the use of rainwater harvesting or greywater recycling [30].

In an effort to discourage particular practices such as the spread of impervious surfaces, some cities are charging fees based on the amount of impervious surfaces per parcel [32]. Conversely, many cities are incentivizing GI through subsidies for rain barrels and rainwater harvesting [33]. Other cities have relied on grant programs for the adoption of green roofs [34]. Increasingly, cities are integrating GI into their planning efforts including transportation plans or as a component of their complete streets policies [35]. Policy changes have led to green belts being conceived more broadly in some cities to include the concept of GI providing corridors for ecological restoration and recreation aimed to mitigate the future impacts of climate change [36]. Because of their above-ground and below-ground biomass, trees are known to reduce runoff very efficiently [37]. Therefore, some municipal policies promote GI through major tree planting programs [28•,29], or ordinances that promote urban tree canopy (from street trees to urban forests) [38,39].

The policy approaches adopted reflect distinct design traditions and socio-environmental contexts as well as different property rights regimes and regulatory behaviors. In some cases, cities find it necessary to adjust their historic centralized governance strategies to support a more decentralized and participatory approach to promote GI [40]. A diverse set of stakeholders, including NGOs and advocacy groups, are increasingly engaged in influencing the framing and production of GI at the urban scale [29]. National and regional policies help to support GI policy development at the urban scale [41].

Performance

In contrast to natural systems, engineered systems are designed to recover from shocks and disturbances to maintain system function. Engineering resilience is affected by society's expectations and demands, the economics of investment, the technical ability to design components and the organization's ability to design and react to conditions [6]. Similar to natural systems, society's role in resilience analysis is complex due to the infrastructure system's societal, environmental and economic impacts. Bruneau *et al.'s* [3] seminal work isolated four factors (or 4Rs) contributing to engineering resilience: (1) robustness, (2) redundancy, (3) resourcefulness, and (4) rapidity. Robustness is the ability to minimize a disruption's impact due to the system or its components capacities. This capability limits a disruption's impact on the system's ability to meets its goal as well as the likelihood of failure. Robustness is similar to natural systems (or ecological)' resilience. The remaining properties are unique to engineering systems. Providing redundant components avoids degradation during elemental failures. While robustness and redundancy mitigate the reduction in functionality, resourcefulness and rapidity involve improving functionality or, during failure, returning the system to an acceptable condition. Resourcefulness relates to the capacity to identify and react to conditions that threaten or have disrupted the system. Rapidity relates to the speed that the failed system is returned to a functioning state through physical repair or operational manipulation.

In green-grey-blue hybrid systems, the four Rs described above are supported by GI. As a decentralized approach to stormwater management, GI enhances robustness of grey infrastructure by increasing the system's capabilities, such as flood reduction or transportation mobility. Likewise, GI provides redundant components to grey infrastructure systems; impart resources to identify problems and establish priorities; and increases the speed to achieve goals, while avoiding future disruptions [3]. To assess the level of urban resilience from GI systems would require defining the level of acceptability of the 4Rs individually or as an aggregated resilience metric. In addition, the decentralized nature of GI systems presents a challenge for ownership and maintenance that are not present in grey infrastructure. This social component requires embedding participatory processes into engineering assessments to ensure inclusivity and appropriateness [11]. Therefore, assessing GI performance in hybrid systems would require additional resources for co-production of decision-making criteria, and the use of metrics that include social dimensions [11].

Connectivity

A connected network of GI is important for people and the environment and is related to urban resilience [4]. Increasing the connectivity between habitat patches at the urban and regional level (between parks to larger nature preserves) is known to reduce the isolation effects of fragmentation and habitat loss [7]. GI can also provide multiple ecosystem services that enhance the quality of life of urban residents, particularly when GI projects are multifunctional [42]. This dimension of connectivity of GI systems aligns with the concept of 'systems of cities,' in which cross-scale interactions link cities and ecological reserves together, allowing the flow of ecosystem services, information, energy, matter, people, wildlife, and innovation [43].

Measuring the effects of a connected GI network on urban resilience is not easy because it involves both ecological and social dimensions. Carlier and Moran [7] developed a method that involves defining landscape types and analyzing the configuration and connectivity of the network. This method can be used to develop recommendations that preserve landscape connectivity and allow for monitoring of future changes [43]. Feng *et al.* [8] explored the ecological potential of brownfield redevelopment projects considering the ecological importance (potential of preventing ecological degradation and achieving ecological balance), and patch importance (location of the project with respect to the GI network) [8].

To measure the social benefits of a GI network, Rall *et al.* [42] propose adding social values to urban GI planning, emphasizing the need for collaborative and socially inclusive processes. Another method to assess connectivity is agent-based models that consider individuals and ecological patches. This method can result in a more realistic simulation of the complex social-ecological processes, focusing on individuals' decision-making [20]. The connectivity of social and spatial relationships can be complex and there is a need to unpack that complexity to understand system function. Simulation models are one approach to do so, but likewise, frameworks that guide the articulation of specific resilience domains can serve as analytical starting points [44].

Social

The concept of social, or community, resilience has been widely used to describe communities' abilities to withstand, respond, and adapt to change [45]. Based on this rapidly expanding body of scholarship and practice, resilience is a socially driven response that can enable social groups to cope with and recover from change, uncertainty, crisis, and disaster while maintaining some acceptable level of functionality [46,47••,48]. The social components of resilience allow for the mobilization of key resources during times of crisis, as well as enabling communities to adapt to future changes through preparedness and planning [48–51]. Social resilience can be measured through assessments of these social networks that connect resources to vulnerable social groups [46], pre-existing social vulnerabilities and exclusion [52], and by local and regional governance systems [45]. Because many urban systems exhibit strong patterns of segregation, it is important to recognize the differential impact of environmental conditions on different populations and the role that resilience plays in issues of environmental justice [45].

GI can contribute to social resilience by reducing pre-existing social vulnerabilities [2••]. In an urban context, GI can influence aspects of social vulnerability such as crime rates and violence [53,54], limits to physical activity and public health [55], and barriers to building social capital and cohesion [56]. Urban community resilience depends on addressing these vulnerabilities by addressing social diversity, adaptability and cohesion in the planning and preparedness process. But, as Meerow and Newell [2••] observe, the multifunctionality of GI can be a challenge for the planning process, as it integrates aspects of both ecological and social resilience that require input from a diverse set of stakeholders and institutions. Questions of equal access and benefit, often framed in terms of 'resilience for whom,' can also make considerations of how to enhance social resilience through GI problematic without careful attention to pre-existing social vulnerabilities [57•]. Thus, to better assess the contributions of GI into the future, practitioners and academics need to consider aspects of social exclusion and vulnerability and the ways in which planning for GI can improve equal access and public engagement while addressing ecological needs.

Conclusions

We have explored the state of the art around four key dimensions of GI that can be used to analyze and measure the effects of GI systems on urban resilience. We find that GI can help support urban resilience across a broad set of actions from the development of policy at the municipal scale that add social dimensions to GI planning, and this way, enhance the likelihood of creating more inclusive and appropriate (context-specific) GI systems that consider the most vulnerable populations. It is important to recognize GI as just one component in considering urban areas as coupled natural-human systems and CIS. GI has explicit dimensions of both social and physical systems and the four dimensions we outline above provide a pathway to understand the role of GI in the context of urban systems resilience.

Beyond their individual features and contributions to supporting urban resilience, we observe interactions across the various dimensions that may serve to support further resilience. For example, institutional support is needed to regulate and foster GI, to ensure engineering systems embrace inclusivity, and to support connectivity, and social networks. Likewise, the effective performance of hybrid systems during disasters ensures the continuous connectivity and the functioning of social networks that can help cities recover faster. Similarly, social cohesion and resilience enables the co-production of assessment methods for engineering systems, and the participation of the community in the creation of GI policies.

We conclude that any assessment or evaluation of urban resilience from GI systems should involve the four dimensions examined here (policy, performance, connectivity, and social) with special attention to participatory processes that involve diverse populations, and that ensure co-production of policies, performance criteria, connectivity, and social resilience, to avoid increased social vulnerability of disadvantaged groups and exacerbated injustices. Existing literature on the role of GI in urban resilience consider some aspects of these four dimensions, we see utility in adopting a broader perspective that incorporates a more expansive or comprehensive perspective. This approach can encourage the development of urban GI policies that reflect the needs of all community members, and GI systems that enhance urban resilience.

Conflict of interest statement

Nothing declared.

Acknowledgements

This work was funded by the Agnese Nelms Haury Program in Environment and Social Justice at the University of Arizona. We also received support from the International Water Security Network funded by Lloyd's Register Foundation, a charitable foundation helping to protect life and property by supporting engineering-related education, public engagement, and the application of research. We also received support from the Inter American Institute for Global Change Research (IAI) CRN3056, which is supported by the National Science Foundation [GEO-1128040]. The paper also benefited from support by the Morris K. Udall and Stewart L. Udall Foundation in Tucson, Arizona; and by the UMI-iGlobes, a French National Center for Scientific Research at the University of Arizona.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Meerow S: **Double exposure, infrastructure planning, and urban climate resilience in coastal megacities: a case study of Manila**. *Environ Plan Econ Space* 2017, **49**:2649-2672.

2. Meerow S, Newell JP: **Urban resilience for whom, what, when, where, and why?** *Urban Geogr* 2019, **40**:309-329
••
This study introduces the five Ws (whom, what, when, where, and why), as considerations for urban resilience plans, initiatives and projects. The authors call for a collective negotiation of these Ws to ensure all voices are heard.

3. Bruneau M, Chang SE, Eguchi RT, Lee GC, O'Rourke TD, Reinhorn AM *et al.*: **A framework to quantitatively assess and enhance the seismic resilience of communities**. *Earthquake Spectra* 2003, **19**:733-752.

4. Olazabal M, Chelleri L, Sharifi A: **Is connectivity a desirable property in urban resilience assessments?** In *Resilience-Oriented Urban Planning - Theoretical and Empirical Insights.* Edited by Yamagata Y, Shafiri A. Springer; 2018:195-211.

5. Organization for Economic Cooperation and Development. Resilient Cities [Internet]. n.d. [cited 2020 Feb 27]. Available from: https://www.oecd.org/cfe/regional-policy/resilient-cities.htm.

6. Tierney K, Bruneau M: *Conceptualizing and Measuring Resilience: A Key to Disaster Loss Reduction*. . Available from: TR News; 2007:14-17 In: *https://trid.trb.org/view/813539*.

7. Carlier J, Moran J: **Landscape typology and ecological connectivity assessment to inform Greenway design**. *Sci Total Environ* 2019, **651**:3241-3252.

8. Feng S, Hou W, Chang J: **Changing coal mining brownfields into green infrastructure based on ecological potential assessment in Xuzhou, Eastern China**. *Sustainability* 2019, **11**:2252.

9. Pakzad P, Osmond P: **Developing a sustainability indicator set for measuring green infrastructure performance**. *Procedia - Soc Behav Sci* 2016, **216**:68-79.

10. Pierre S, Groffman PM, Killilea ME, Oldfield EE: **Soil microbial nitrogen cycling and nitrous oxide emissions from urban afforestation in the New York City afforestation project**. *Urban For Urban Green* 2016, **15**:149-154.

11. Ward S, Staddon C, De Vito L, Zuniga-Teran A, Gerlak AK, Schoeman Y *et al.*: **Embedding social inclusiveness and appropriateness in engineering assessment of green infrastructure to enhance urban resilience**. *Urban Water J* 2019, **16**:56-67.

12. Zhang X, Li H: **Urban resilience and urban sustainability: what we know and what do not know?** *Cities* 2018, **72**:141-148.

13. Elmqvist T, Andersson E, Frantzeskaki N, McPhearson T, Olsson P, Gaffney O *et al.*: **Sustainability and resilience for transformation in the urban century**. *Nat Sustain* 2019, **2**:267-273.

14. Tellman B, Bausch JC, Eakin H, Anderies JM, Mazari-Hiriart M, Manuel-Navarrete D *et al.*: **Adaptive pathways and coupled infrastructure: seven centuries of adaptation to water risk and the production of vulnerability in Mexico City**. *Ecol Soc* 2018, **23**:art1.

15. Heymans A, Breadsell J, Morrison GM, Byrne JJ, Eon C: **Ecological urban planning and design: a systematic literature review**. *Sustainability* 2019, **11**:3723.

16. Leichenko R: **Climate change and urban resilience**. *Curr Opin Environ Sustain* 2011:164-168
•
This study identifies challenges for the practical application of resilience approaches, including equity, financeability, innovation, and sustainability. The authors recommend combining efforts to enhance urban resilience with efforts to promote urban development.

17. Staddon C, De Vito L, Zuniga-Teran A, Schoeman Y, Hart A, Booth G: *Contributions of green infrastructure to enhancing urban resilience [Internet]*. . p. 19. (The Resilience Shif: Agenda Setting Scoping Studies). Available from: 2017 In: *http://resilienceshift.org/wp-content/uploads/2017/10/043_Contributions-of-Green-Infrastructure-to-Enhancing-Urban-Resilience.pdf*.

18. Ahern J: **Urban landscape sustainability and resilience: the promise and challenges of integrating ecology with urban planning and design**. *Landsc Ecol* 2013, **28**:1203-1212.

19. Abraham A, Sommerhalder K, Abel T: **Landscape and well-being: a scoping study on the health-promoting impact of outdoor environments**. *Int J Public Health* 2010, **55**:59-69.

20. Tidball KG, Aktipis A: **Feedback enhances greening during disaster recovery: a model of social and ecological processes in neighborhood scale investment**. *Urban For Urban Green* 2018, **34**:269-280.

21. Zuniga-Teran A, Staddon C, De Vito L, Gerlak AK, Ward S, Schoeman Y *et al.*: **Challenges of mainstreaming green infrastructure in built environment professions**. *J Environ Plann Manag* 2019.

22. Lovell ST, Taylor JR: **Supplying urban ecosystem services through multifunctional green infrastructure in the United States**. *Landsc Ecol* 2013, **28**:1447-1463.

23. Zuniga-Teran AA, Gerlak AK: **A multidisciplinary approach to analyzing questions of justice issues in urban greenspace**. *Sustainability* 2019, **11**:3055.

24. Artmann M, Kohler M, Meinel G, Gan J, Ioja I-C: **How smart growth and green infrastructure can mutually support each other — a conceptual framework for compact and green cities**. *Ecol Indic* 2019, **96**:10-22.

25. Simpson NP, Simpson KJ, Shearing CD, Cirolia LR: **Municipal finance and resilience lessons for urban infrastructure management: a case study from the Cape Town drought**. *Int J Urban Sustain Dev* 2019:1-20.

26. Béné C, Mehta L, McGranahan G, Cannon T, Gupte J, Tanner T: **Resilience as a policy narrative: potentials and limits in the context of urban planning**. *Clim Dev* 2018, **10**:116-133.

27. Wilson D, Jonas AEG: **Urban resilience: an urban political movement**. *Urban Geogr* 2018, **39**:1265-1267.

28. Anderies JM, Janssen MA, Schlager E: **Institutions and the**
• **performance of coupled infrastructure systems**. *Int J Commons* 2016, **10**:495

This study examines the concept of coupled infrastructure systems (CIS), and the role of institutions as one class of infrastructure that dynamically interacts with the other infrastructures to produce outcomes that affect urban systems.

29. Mell I: **Green infrastructure planning: policy and objectives**. In *Handbook on Green Infrastructure: Planning, Design and Implementation.* Edited by Sinnett D, Smith N, Burgess S. UK: Edward Elgar Publishing; 2013:105-123.

30. Charlesworth S, Booth C, Warwick F, Lashford C, Lade O: **Chapter 12: rainwater harvesting - reaping a free and plentiful supply of water**. In *Water Resources in the Built Environment: Management Issues and Solutions.* Edited by Booth C, Charlesworth S. United Kingdom: John Wiley & Sons, Inc; 2014.

31. Staddon C, Ward S, De Vito L, Zuniga-Teran A, Gerlak AK, Schoeman Y *et al.*: **Contributions of green infrastructure to enhancing urban resilience**. *Environ Syst Decis* 2018, **38**:330-338.

32. Vogel JR, Moore TL, Coffman RR, Rodie SN, Hutchinson SL, McDonough KR *et al.*: **Critical review of technical questions facing low impact development and green infrastructure: a perspective from the great plains**. *Water Environ Res* 2015, **87**:849-862.

33. Baptiste AK, Foley C, Smardon R: **Understanding urban neighborhood differences in willingness to implement green infrastructure measures: a case study of Syracuse, NY**. *Landsc Urban Plann* 2015, **136**:1-12.

34. Tayouga S, Gagné S: **the socio-ecological factors that influence the adoption of green infrastructure**. *Sustainability* 2016, **8**:1277.

35. Wise S: **Green infrastructure rising - best practices in stormwater management**. *Planning* 2008, **7**.

36. Amati M, Taylor L: **From green belts to green infrastructure**. *Plan Pract Res* 2010, **25**:143-155.

37. Scharenbroch BC, Morgenroth J, Maule B: **Tree species suitability to bioswales and impact on the urban water budget**. *J Environ Qual* 2016, **45**:199.

38. Kolosna C, Spurlock D: **Uniting geospatial assessment of neighborhood urban tree canopy with plan and ordinance evaluation for environmental justice**. *Urban For Urban Green* 2019, **40**:215-223.

39. Pregitzer CC, Ashton MS, Charlop-Powers S, D'Amato AW, Frey BR, Gunther B *et al.*: **Defining and assessing urban forests to inform management and policy**. *Environ Res Lett* 2019, **14**:085002.

40. Dhakal KP, Chevalier LR: **Urban stormwater governance: the need for a paradigm shift**. *Environ Manage* 2016, **57**:1112-1124.

41. Nickel D, Schoenfelder W, Medearis D, Dolowitz DP, Keeley M, Shuster W: **German experience in managing stormwater with green infrastructure**. *J Environ Plan Manage* 2014, **57**:403-423.

42. Rall E, Hansen R, Pauleit S: **The added value of public participation GIS (PPGIS) for urban green infrastructure planning**. *Urban For Urban Green* 2019, **40**:264-274.

43. Ernstson H, van der Leeuw SE, Redman CL, Meffert DJ, Davis G, Alfsen C *et al.*: **Urban transitions: on urban resilience and human-dominated ecosystems**. *Ambio* 2010, **39**:531-545.

44. Masnavi MR, Gharai F, Hajibandeh M: **Exploring urban resilience thinking for its application in urban planning: a review of literature**. *Int J Environ Sci Technol* 2019, **16**:567-582.

45. Caniglia B, Vallee M, Frank B (Eds): *Resilience, Environmental Justice and the City*. Taylor and Francis; 2016.

46. Adger WN: **Social and ecological resilience: are they related?** *Prog Hum Geogr* 2000, **24**:347-364.

47. Berkes F, Ross H: **Community resilience: toward an integrated**
•• **approach**. *Soc Nat Resour* 2013, **26**:5-20

This study explores an integrated approach for the concept of community resilience combining theories from social-ecological systems and psychology of development and mental health. Findings show that this integrated approach enables the identification of social strengths and connections to place.

48. Magis K: **Community resilience: an indicator of social sustainability**. *Soc Nat Resour* 2010, **23**:401-416.

49. Abramson DM, Grattan LM, Mayer B, Colten CE, Arosemena FA, Bedimo-Rung A *et al.*: **The resilience activation framework: a conceptual model of how access to social resources promotes adaptation and rapid recovery in post-disaster settings**. *J Behav Health Serv Res* 2015, **42**:42-57.

50. Barr S, Devine-Wright P: **Resilient communities: sustainabilities in transition**. *Local Environ* 2012, **17**:525-532.

51. Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T, Rockström J: **Resilience thinking: integrating resilience, adaptability and transformability**. *Ecol Soc* 2010, **15**:art20.

52. Cutter SL, Barnes L, Berry M, Burton C, Evans E, Tate E *et al.*: **A place-based model for understanding community resilience to natural disasters**. *Glob Environ Change* 2008, **18**:598-606.

53. Burley BA: **Green infrastructure and violence: do new street trees mitigate violent crime?** *Health Place* 2018, **54**:43-49.

54. Kuo FE, Sullivan WC: **Environment and crime in the inner city: does vegetation reduce crime?** *Environ Behav* 2001, **33**:343-367.

55. Coutts C: *Green Infrastructure and Public Health [Internet].* . 326 p. Available from: London: Routledge; 2016 In: *https://www.taylorfrancis.com/books/9781315647623*.

56. Coutts C, Hahn M: **Green infrastructure, ecosystem services, and human health**. *Int J Environ Res Public Health* 2015, **12**:9768-9798.

57. Mayer B: **A framework for improving resilience: adaptation in**
• **urban contexts**. In *Resilience, Environmental Justice and the City [Internet].* Edited by Caniglia B, Vallee M, Frank B. Routledge; 2016:45-64. . Available from: In: *https://www.taylorfrancis.com/books/e/9781315652054/chapters/10.4324/9781315652054-10*

This chapter highlights environmental justice issues that exist in pathways toward resilience, and calls for the need to consider past, present, and future implications of injustices when developing resilience strategies.