Conceptualizing a Model of Antifragility for Dense Urban Areas

Allan W. Shearer[1], David J. Kilcullen[2], Gordon Pendleton[3]

[1]The University of Texas at Austin, Texas/USA · ashearer@austin.utexas.edu
[2]Cordillera Applications Group, Colorado/USA
[3]Cordillera Applications Group, Hampshire/UK

Abstract: Understanding how cities respond to stress can inform possible planning, design, and management changes to advance health, safety, and welfare. This paper considers antifragility, which is a property of some systems to improve when exposed to volatility, as a means to understand dynamics of dense urban areas. It presents a computational framework to assess if urban systems are becoming fragile or antifragile by tracking changes in service capacities following disruption. The Political, Military, Economic, Social, Infrastructure, and Information (PMESII) categorization is adapted to reference capabilities and extended to pose and test hypotheses about system orders for urban areas.

Keywords: Antifragility, resilience, urban systems, PMESII

1 Introduction

This paper presents a framework for a computational model of antifragility (TALEB 2012), which is a property of some systems in which they improve when exposed to volatility, for dense urban areas. The work is motivated by the increasing size and density of contemporary cities, by the vulnerability of cities to natural and anthropogenic disasters, and by the expanding roles of large cities in national and international economic, environmental, and security matters. It is done on the premise that tracking the ways urban populations develop or lose capabilities and capacities to overcome disruptions of various types, magnitudes, frequencies, and durations can provide a basis for improved planning, design, and management.

Nicholas N. Taleb coined the term *antifragile* based on the behavior of open financial markets, but he argues for its general applicability. He distinguishes antifragile systems from fragile and robust systems based on the potential effects of uncertainty including volatility, disturbance, and stress, and he uses characters from Greek mythology as introductory examples. Fragile systems, like Damocles under the sword, have great exposure to loss due to uncertainty and do not benefit from exposure to it. Robust systems, like the Phoenix that rises after death, resist harm from uncertainty, but have limited gains from it. Antifragile systems, like the Hydra, are systems that grow or otherwise benefit from exposure to damage. A non-mythic example of an antifragile system is a person who exercises regularly: the body undergoes a temporary metabolic shift as it moves faster or lifts weight. As a result, the person becomes able to run farther and lift heavier objects. Significantly, as an outcome of the temporary stress, the body becomes more generally fit and able to do some things that were not explicitly prescribed in the training regime nor necessarily anticipated, such as having improved stamina to assist in an unforeseen emergency. System qualities that contribute to antifragility include being emergent rather than resultant, risk allowing rather than risk averse, enabling small-scale rather than system-wide experiments, even rather than uneven distribution of resources, redundancy rather than efficiency, loosely rather than tightly coupled components, and variety and variability rather than uniformity.

Journal of Digital Landscape Architecture, 6-2021, pp. 75-84. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-705-2, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537705004.

2 Sustainability, Resilience, and Antifragility

Urban areas can be understood as systems that are: (1) *purposeful*, because they are created to satisfy societal goals; (2) *emergent*, because the behaviour of the whole cannot be reduced to the behaviour of individual elements; (3) *complex*, because individual elements have many relationships with other elements; (4) *open*, because they exchange energy, materials, and information with their context; and, (5), *self-organizing*, because, they can modify their internal structures or functions in response to external change. Across these qualities, patterns of resource distribution and flows of people, water, food, energy, goods, waste and information emerge from processes and can be observed and measured. (BARTHELEMY 2017, BATTY 2013).

Urban systems can exhibit nonlinear dynamics, reciprocal feedback loops, time lags, heterogeneity, and surprises (JIANGUO et al. 2007). These qualities combine to create uncertainty and volatility that can allow for the emergence of both positive outcomes, such as economic growth through innovation (CHRISTIAANSE 2009), and negative outcomes, such as the disruption and degradation of basic services that could contribute to the formation of so-called "feral cities" (NORTON 2003).

It is argued here that a consideration of antifragility expands the management of uncertainty in environmental planning, design, and management through the paradigms of sustainability and resilience by foregrounding ontological uncertainty. Figure 1 provides an illustration noting the dominant consideration of uncertainty in each paradigm. Relative foci of attention are indicated on lines connecting the three terms.

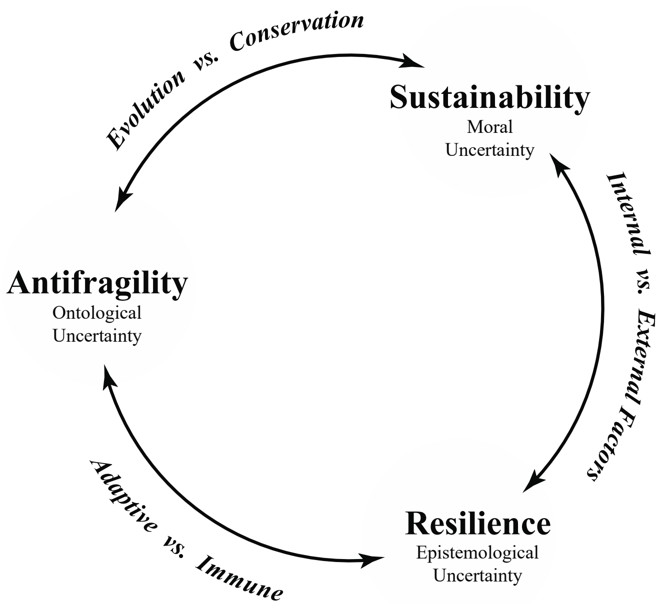

Fig. 1: Normative objectives of urban planning, design, and management and the associated predominant sources of uncertainty (Source: Authors)

The concept of sustainability can be understood as a focus on the long-term conservation of resources needed to support a system. The premise was common in texts on agriculture, forestry, and other natural resources fields since, at least, the 16th century (DIXON & FALLON 1989, WARDE 2011), but the term, itself, gained widespread attention in the late 1980s through *Our Common Future* (WORLD COMMISSION ON ENVIRONMENTAL DEVELOPMENT 1987). There is general consensus that sustainability is organized around the "triple bottom line" of environment, equity, and economics with the aim of not reducing resources or limit decisions of future generations. Determining how to define what is "right" or "just" or "best" in any one of these goals (or of any societal goal) presents moral or ethical uncertainty (HACKING & GUTHRIE 2008, MOELLENDORF 2011, VEENMAN & LEROY 2016).

The concept of resilience concerns a focus on abilities to withstand, recover, and adapt from external shocks. Consideration of it becomes increasingly important as a system's internal organization becomes more complex and as its exchanges with the system's environment become uncertain or volatile (HOLLING 1973, PICKETT et al 2004). With resilience, the moral questions emphasized under the paradigm of sustainability about which and how societal goals are prioritized are replaced by epistemological questions related to the difficult task of knowledge production about vulnerabilities and threats for purposes of governance (ARADAU 2014, CHANDLER 2014, WELSH 2014).

As noted, the concept of antifragility concerns the possibility that a system cannot only recover from disturbance, it can benefit from exposure to uncertainty and volatility by developing capabilities and capacities to manage stress, including stress that had previously not been experienced or that even imagined. This quality distinguishes antifragility from resilience and warrants emphasis. It is widely acknowledged that some understandings of resilience include the possibility of adaptation that enables the system to better withstand future shocks. The improvement, though, is an improvement to address epistemological uncertainty related to the ability to anticipate, guard against, and recover from the same kind of disruption. Medical vaccination is an example. The introduction of a harmful, but weakened or neutralized pathogen into a body allows a person to develop antigens that enable resistance to stronger doses of the same pathogen in the future. In these instances, the potential cause of harm (the specific virus) and the possible effect of harm (the specific infection) are narrowly defined. A flu shot in the autumn helps prevent contracting flu in the winter, but the same shot does not protect against measles. With antifragility, attention shifts from resilience's epistemological uncertainty to questions of ontological uncertainty related to the environment and its interaction with the composition, organization, and behavior of the system. Succinctly, becoming more antifragile is not adapting to handle the same sort of crisis better, but to better handle crises in general.

3 Application to Urban Planning and Design

Since its introduction, antifragility has been discussed within domains of knowledge and practice ranging from genetics (DACHIN et al. 2011) to athletic performance (HILL et al. 2020) to business operations (JAARON & BACKHOUSE 2014) to computer science (HOLE 2016) to homeland security (EGAN 2013). In urban and landscape planning and design literature, emphasis has been given to the adding options to respond to disruption as a way to increase antifragility (BLECIC & CECCHINI 2017, BLECIC & CECCHINI 2020, ROGGEMA 2019). Following from this premise, the initial task of moving from an aspirational model to an operational model of antifragility for urban areas becomes developing a framework to collect and relate data that indicate the gain or loss of optionality.

Figure 2 provides a diagram of the basic needs for tracking the development of a system becoming more antifragile by gaining options or, conversely, more fragile by losing options. At the top of the diagram are indicators of societal capacities, on the right hand side are kinds of change, at the bottom of the diagram are the system's responses to change, which are qualified on the left hand side. Issues related to each of these data types are discussed below. Data sources would include remotely sensed data, aggregated news resources, objects connected to the Internet-of-Things (IoT), routing options for flows, observational surveys, and interviews of personal perception. The volume of data is expected to be large. Growth of IoT sources offers the promise of increased objective measurements, but initial operational tests of the framework might focus on surveys of perceptions across an urban area to understand what how disruptions are locally recognized and managed.

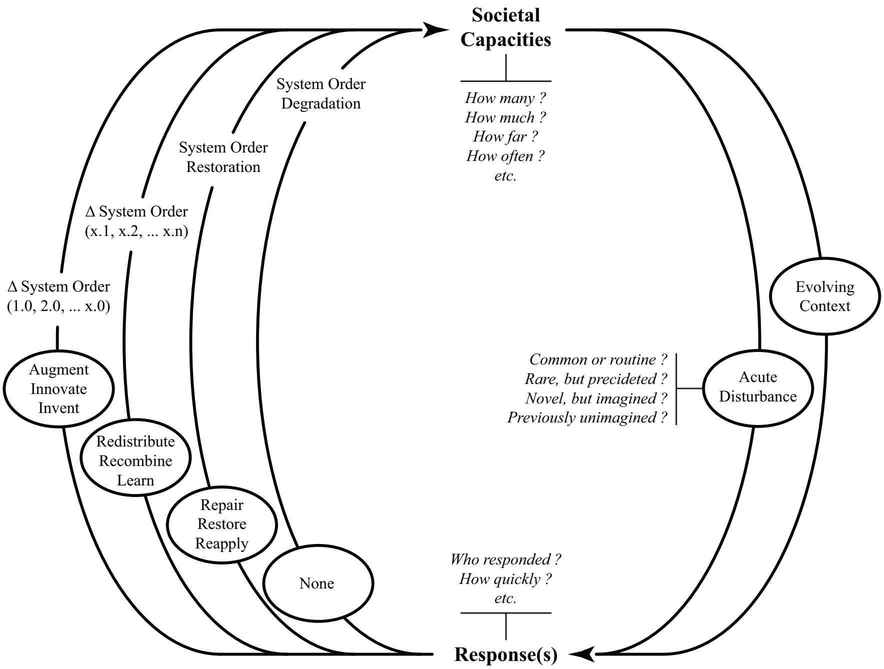

Fig. 2: Framework to observe system response to disruption (Source: Authors)

Defining classes of indicators throughout the framework can be done only provisionally for two reasons. First, epistemological uncertainty, a concern shared with efforts to improve resilience, limits ability to accurately identify and parameterize cause and effect relationships within complex urban areas. Second, ontological uncertainty limits ability to anticipate all forms of future volatility and how resources might be used to manage disruptions.

Additionally, the expected qualities of an antifragile system (being emergent, risk allowing, enabling small-scale experiments, even distribution of resources, redundancy, loosely coupling components, and variety and variability) point to the need to collect the data at multiple spatial scales over time. Figure 3 illustrates one approach to do so based on common urban administrative units: politically recognized neighbourhoods, districts, the city as a whole, and the metropolitan region around the city. An advantage of this approach is that these units may be commonly used by municipal service providers. Another approach would be to map "neighbourhoods" based on activities. An example is offered by an assessment of national districts in the United Kingdom. The authors of this study used density of telecommunication contacts and produced a map that was similar to, but not identical with long-established political jurisdictions (RATTI et al. 2010). The advantage of these units of analysis would be greater fidelity to social or socio-economic groupings. A third approach would be to use floating averages of indicators taken at different areal extents, such as 1 hectare, 10 hectares, and 100 hectares. The advantage with this approach would be to identify or track aggregate hot- and cold-spots of resource availability and system responses.

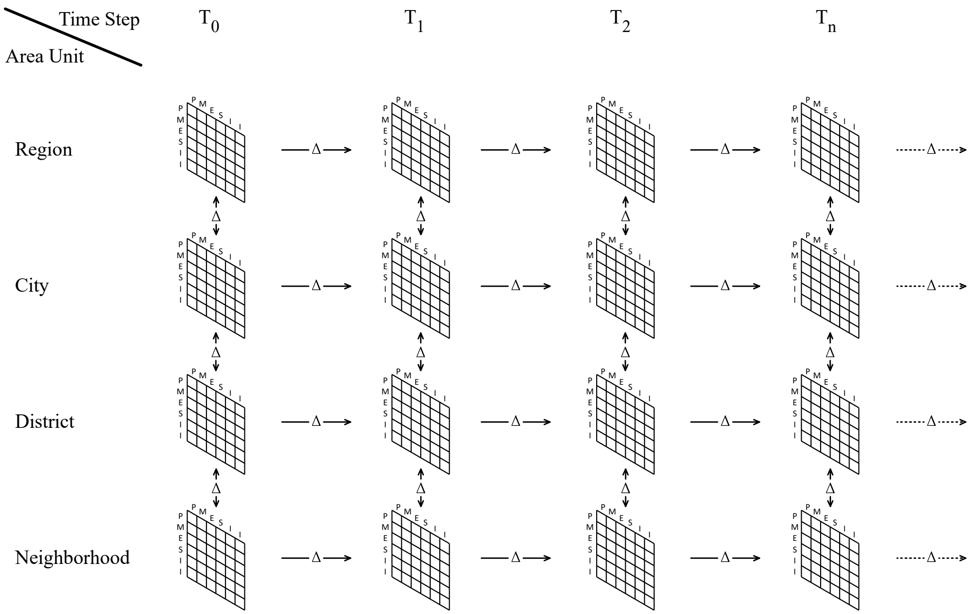

Fig. 3: Spatial scales of urban order (Source: Authors)

Tracking increases or decreases in options to overcome volatility is done through the societal capacities indicators. Four classes of indicators or proposed. The first class consists of spatially fixed resource capacities that would be recorded by number per area (neighbourhood, district, etc.) and number per population. Examples include fire and police stations and hospitals. Non-emergency fixed resources include grocery stores and schools. It would be important to inventory how things are used, not just how they are most often classified on a land use map. For example, a parking lot might sometimes be used as a market. This class of indicators also includes people who staff these resources, such as fire-fighters, which might also be distinguished by time as well as space if, say, night shifts have fewer personnel than day shifts. The second class of indicators consists of measures of diversity of spatial resources. This class is arguably the most difficult to conceptualize with regard to measures of fragility or antifragility. For basic services, having access of a variety of service providers, such as internet service providers, provides a range of options. Similarly, having a transportation network that allows more ways to travel from one point to another provides a range of options. But not all services are equally exchangeable. For example, having multiple places of worship for the same religion or sect provides a choice of providers for assembly, but does not offer the same kind of choice across religions. As such, indicators of social diversity need to be supplemented with indicators of interoperability, integration, and inclusion. The third class of indicators would be service frequency. Examples include police patrol passes per day or per week or the number of times streets are cleaned per week or month. The fourth class of indicators would be perceptions of residents about structural and functional capacities. In part, this class of indicators serves to assess if those who live in the city note or utilize available resources. Also in part, it provides a way to assess not only the use of resources, but also the trust in different service providers. For example, who might be contacted to help resolve a neighbourhood dispute?

Moving clockwise around figure 2, two kinds of volatility are noted. At the far right are relatively slowly moving contextual factors. These include trends related to politics, economics, society, and technology. On the inside are fast moving, acute disturbances or shocks. Although abrupt events are the topic of Taleb's writing, innovation and reorganization in urban areas follows from both slow and fast moving endogenous and exogenous change (BOND-FORTIER 2020, DORAC et al. 2017, TENG-CLLEJA et al. 2017). The selection of indicators for both kinds of disruption need to be connected to loads of the previously identified service capacities. As with the indicators of social capacity, it would be valuable to understand relationships between fact and perception. For example, what connections do residents draw between kinds and magnitudes of evolving change and abrupt disruptions?

At the bottom and left of the diagram are the system's responses to the disruption. There are two classes of indicators. The first is the immediate response – who responds, how quickly, with what means, etc. The second, qualified on the left hand side of the diagram, are four possibilities for remediation and recovery: the city can do nothing in response to exogenous change, it can maintain or restore capacity, it can learn, recombine, or redistribute existing resources to become more efficient, or it can innovate and fundamentally reorganize. It might be expected, but would need to be tested, the degrees to which each of these options is pursued given the dynamics of both routine conditions and crises (ROSEN 1988). Any changes made to the urban system will be reflected in revised social capacity indicators.

While it can be said that from a planning, design, and management perspective, becoming more antifragility by increasing options to respond to disruptions is beneficial, it must be recognized that antifragility is achieved by allowing failures to occur through small scale experimentation, so progress might be uneven. Further, improving antifragility of a system involves allowing some components to be fragile. That is, the survival of the whole is achieved by transferring vulnerability to some parts (see chapter 4 in TALEB 2012). This aspect of antifragility has been viewed by some as controversial (KOLERS 2016).

4 Hypotheses of Urban Order that Contribute to Antifragility

Towards the ability to move beyond descriptive statistics to a fuller science of cities (BATTY 2013), there is the need to state and test hypotheses about changes to the built environment. With regard to the framework presented here, if capacities to support societal goals are assumed to result from system order, the indicators should be framed within an understanding of urban systems organization. Such a framework would allow hypotheses for ways capabilities are created or lost through combinations of structural features and behaviours.

As an example, one approach would be to employ a modified version of the Political-Military-Economic-Social-Infrastructure-Information (PMESII) framework, which was developed by the US Army to describe operational environments – places known to be volatile. PMESII is typically used to provide a structural inventory of factors. To understand the city as a dynamic coupled human-natural system, two modifications or extensions will need to be taken. First, the structural descriptions are rewritten as "How…?" questions. For example, the conventional Military description, "Explores the military and/or paramilitary capabilities of all relevant actors (enemy, friendly, and neutral) in a given operational environment" (US Army 2013) is reconsidered as, "How are security issues defined, declared, engaged, and resolved?" (Shearer 2021). Rephrased questions are given in Table 1.

Table 1: Functional PMESII questions (Source: Authors)

Variable	Defining Question
Political (P)	How is a member (typically a citizen) identified, what rights pertain to a member, and how do these rights differ from non-members?
Military (M) [Public Safety Agencies]	How are security issues defined, declared, engaged, and resolved?
Economic (E)	How do people exchange goods and services?
Social (S)	How do individuals and groups behave and why do they do what they do?
Infrastructure (Infra)	How are flows – of people, food, water, goods, power – coordinated throughout the city?
Information (Info)	How is truth recognized?

In the second modification or extension of the framework, questions related to system function are asked across the six primary topics. For example, the Political-Social interaction question is, "How is order legitimized?" In part, these questions provide a basis to deepen the analysis of the six primary areas and may reveal more nuanced issues of strength or of vulnerability. They also offer lines of inquiry to consider second- and third-order effects of change or disruption. Separate from tracking indicators of capacity, a high number of news stories from a given city related to one of these questions would signal an expectation of system change.

With respect to urban planning theory, it is offered that three triplets of PMESII interactions provide a provisional basis to hypothesize and test kinds of system order. These are shown in figure 4. The first is order established/expanded from above through the Political-Military-Infrastructure triplet (after Allen & Cochrane 2010, Guldi 2012, Scott 1998). The second is order established/expanded from below through the Economic-Social-Information triplet (after Jacobs 1961, Jacobs 1969). Third, and in recognition of emerging smart city and cyber systems, there are two possible ways to establish/expand order from within. Social-Infrastructure-Information permits platforms such as Facebook to enable capabilities and capacities (after Helmond et al. 2019). Political-Infrastructure-Information permits a new form of centralized ("smart") governmental influence (after Chen & Shan 2019, Qui 2007). While these sources of order are supported by the literature, it is possible that more influential relationships that support capacity change could be identified through longitudinal analysis of individual cities or through comparative analysis of different urban areas.

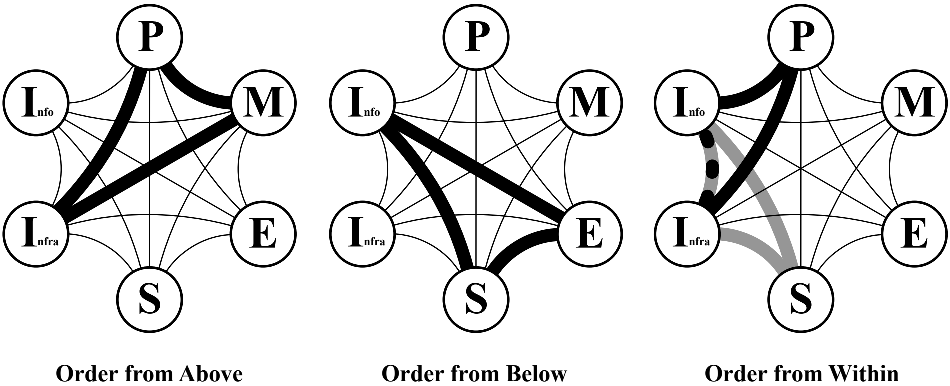

Fig. 4: Sources of urban system order (Source: Authors)

It should be emphasized that the approach outlined here does not pre-identify expected tipping points when an urban areas is considered anti-fragile or fragile. Instead it seeks changes in health, safety, and welfare capacities over time and draws attention to those changes. Hard tipping points are not provided because dense urban areas are open, complex, self-organizing, and emergent systems, so it is unlikely that abilities to manage a disturbance or to fail from it will look the same in the future as they did in the past. Related, while commonalities can be found across cities, a variety of factors including localized social expectations, level of industrial and economic development, and political organization make it seem unlikely that all urban areas would fail or succeed in the same way.

5 Conclusion and Outlook

This paper advances discussions on antifragility for urban areas by providing a framework for a computational model, categories of data, and a basis to frame and test hypotheses of evolving system order. Next steps would be to define arrays optionality indicators more precisely and begin collecting data. Given the large volume of observations that might be made, surveys and comparisons of neighborhoods within a given district may offer a step toward surveys including districts within a city and then a city within its metropolitan area.

In the last two decades of the twentieth century, the paradigm of sustainability foregrounded issues of moral uncertainty and aided the advancement of theories and practices for long-term resource management. In the first two decades of this century, the paradigm of resilience foregrounded epistemological uncertainty aided the advancement of governance for complex systems in settings with knowable even if not predictable shocks. Given unprecedented urbanization in the Anthropocene, it is increasingly necessary to consider ontological uncertainty, to look beyond identifiable threats, and to understand the functional dynamics of how cities reorganize and address previously not experienced or unknown stresses. The paradigm of antifragility can help planners, designers, and managers do so.

Acknowledgement

Parts of this work were supported by the US Defense Advanced Research Projects Agency (DARPA) Small Business Technology Transfer (STTR) program through research contract #140D6318C0062.

References

ALLEN, J. & COCHRANE, A. (2010), Assemblages of State Power: Topological Shifts in the Organization of Government and Politics. Antipode, 42 (5), 1071-1089.

ARADAU, C. (2014), The Promise of Security: Resilience, Surprise and Epistemic Politics. Resilience: International Policies, Practices and Discourses, 2 (4), 73-87.

BARTHELEMY, M. (2017), The Structure and Dynamics of Cities: Urban Data Analysis and Theoretical Modeling. Cambridge University Press, Cambridge, UK.

BATTY, M. (2013), The New Science of Cities. MIT Press, Cambridge, MA.

BLECIC, I. & CECCHINI, A. (2017), On the Antifragility of Cities and of Their Buildings. City, Territory and Architecture, 4 (1), article 7.

BLECIC, I. & CECCHINI, A. (2020), Antifragile Planning. Planning Theory 19 (2), 172-192.

BOND-FORTIER, B. J. (2020), Organization Change in an Urban Police Department. Routledge, New York.

CHANDLER, D. (2014), Resilience: The Governance of Complexity. Routledge, New York.

CHEN, J. & SHAN, W. (2020), A Stable Chinese Society in 2019: Under Tightening Control. East Asian Policy 12 (1), 45-58.

CHRISTIAANSE, K. (2009), The Open City and its Enemies. In: CHRISTIAANSE, K., SINGLER, J. & RIENIETS, T. (Eds.), Open City: Designing Coexistence. SUN Architecture, Amsterdam, 25-35.

DANCHIN, A. et al. (2011), Antifragility and Tinkering in Biology (and in Business) Flexibility Provides and Efficient Epigenetic Way to Manage Risk. Genes, 2 (4), 998-1016.

DIXON, J. J. & FALLON, L. A. (1989), The Concept of Sustainability: Origins, Extensions, and Usefulness for Policy. Society & Natural Resources: An International Journal, 2 (1), 73-84.

EGAN, J. T. (2013), Homeland Security as a Stock Market: Antifragility as a Strategy for Homeland Security. Thesis at Naval Post Graduate School, Monterey, CA.

GULDI, J. (2012), Roads to Power: Britain Invents the Infrastructure State. Harvard University Press, Cambridge, MA.

HACKING, T. & GUTHRIE, P. (2008), A Framework for Clarifying the Meaning of the Triple Bottom-Line, Integrated, and Sustainability Assessment. Environmental Impact Review, 28 (2-3), 73-89.

HELMOND, A., NIEBORG, D. B. & VAN DER VLIST, F. N. (2019), Facebook's Evolution: Development of a Platform-as-Infrastructure. Internet Histories: Digital Technology Culture and Society, 3 (2), 123-146.

HILL, Y. et al. (2020), Antifragility in Climbing: Determining Optimal Stress Loads for Athletic Performance Training. Frontiers in Psychology, 11, article 272.

HOLE, K. J. (2016), Anti-fragile ICT Systems. Springer, Cham.

HOLLING, C. S. (1973), Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics, 4 (4), 1-23.

JAARON, A. & BACKHOUSE, C. J. (2014), Building Antifragility in Service Organizations: Going beyond Resilience. International Journal of Services and Operations Management, 19 (4), 491-513.

JACOBS, J. (1961), The Death and Life of Great American Cities. Vintage Books, New York.

JACOBS, J. (1969), The Economy of Cities. Random House, New York.

JIANGUO, L. et al. (2007), Complexity of Coupled Human and Natural Systems. Science, 317 (5844), 1513-1516.

KOLERS, A. (2016), Resilience as a Political Idea. Ethics, Policy & Environment, 19 (1), 91-107.

KORAC, S., SALITERER, I. & WALKER, R. M. (2017), Analysing the Environmental Antecedents of Innovation Adoptions Among Politicians and Public Managers. Public Management Review, 19 (4), 566-587.

MOELLENDORF, D. (2011), A Right to Sustainable Development. The Monist, 94 (3), 433-452.

NORTON, R. J. (2003), Feral Cities. Naval War College Review, 55 (4), 97-106.

PICKETT, S. T. A. et al. (2004), Resilient Cities: Meaning, Models, and Metaphor for Integrating the Ecological, Socio-Economic, and Planning Realms. Landscape and Urban Planning, 69 (4), 369-384.

QIU, J. C. (2007), The Wireless Leash: Mobile Messaging Service as a Means of Control. International Journal of Communication, 1, 74-91.

RATTI, C. et al. (2010), Redrawing the Map of Great Britain from a Network of Human Interactions. PLoS ONE, 5 (12), article e14248.

ROGGEMA, R. (2019), Design for Disruption: Creating Anti-Fragile Urban Delta Landscapes. Urban Planning, 4 (1), 113-122.

ROSEN, S. P. (1988), New Ways of War: Understanding Military Innovation. International Security, 13 (1), 134-168.

SCOTT, J. C. (1998), Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed. Yale University Press, New Haven.

SHEARER, A. W. (2021), Roleplaying to Improve Resilience. Architecture_MPS, 18 (1), article 6.

TALEB, N. N. (2012), Antifragile: Things that Gain from Disorder. Random House, New York.

TENG-CALLEJA, M. M. et al. (2017), Transformation in Philippine Local Government. Local Government Studies, 43 (1), 64-88.

US ARMY (2013), Training Circular No. 7-102: Operational Environment Considerations for Training and Education, Revised. Headquarters of the Army, Washington, D. C.

VEENMAN, S. & LEROY, P. (2016), Environmental Outlooks: How They Frame Futures and Long Term Uncertainty. Futures, 82, 63-75.

WARDE, P. (2011), The Invention of Sustainability. Modern Intellectual History, 8 (1), 153-170.

WELSH, M. (2014), Resilience and Responsibility: Governing Uncertainty in a Complex World. The Geographical Journal, 180 (1), 15-26.

WORLD COMMISSION ON ENVIRONMENTAL DEVELOPMENT (1987), Our Common Future. Oxford University Press, Oxford, UK.