Chapter 5
Linking Sustainability and Resilience of Future Cities

D. Asprone, A. Prota and G. Manfredi

Abstract Resilience and sustainability are now primary goals for future cities. On one hand, the extreme natural and man-made events that have recently hit urban systems (earthquakes, tsunamis, terroristic attacks) makes resilience a principal challenge of our society. On the other hand, the high environmental, social and economic burden that cities have today, combined with the high exposure of the world population in cities, makes sustainability as well a main objective for future development. However, how the two concepts are linked and how we should imagine future cities in terms of resilience and sustainability, represent an issue for scientific debate. An approach aimed at hinging the concept of resilience within a sustainability-based framework is being proposed here, where safety of city inhabitants is considered as a main requirement for sustainability of future cities. Here, the city is seen as a complex and dynamic organism for which sustainability should be ensured at each stage of the urban development. The proposed approach moves from the point that, for the city, an extreme event and the resulting changes moving the city to a new point of dynamic equilibrium, represent a stage in the life cycle, i.e. the Hazardous Event Occurrence phase; hence, it is stated that resilience represents the sustainability of this phase, from the economic, social and environmental point of view, for all the present and future actors, directly and indirectly involved in the recovery process. Furthermore, since urban systems are interconnected with each other by a complex network of relationships, it is also stated that city resilience must be sought on a "glocal" scale, as it also happens for sustainability; that is, the objective of city resilience must be pursued both on a local scale, referring to the physical and social systems within cities, and on the global scale, referring to the system of relationships which connects cities to each other.

Keywords Sustainability · Resilience · Future cities · Disasters

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5.1 Introduction

Nowadays, sustainability is recognized by many scholars and practitioners as one of the prerequisites for the successful development of contemporary society. The concept of sustainability is evoked to characterize and define the optimal relationship between man and nature, in whatever form it is realized. Nevertheless, the concept of sustainability is very complex and the correct implementation of "sustainable" processes and transformations can be extremely difficult. The objective of sustainable development, in fact, in its widest meaning, is to govern a complex system of actors and entities, represented by man and society on one hand and environment and natural resources on the other hand, linked by complex relationships and conflicting dynamics.

The greatest expressions of the conflict between development and conservation is most present in the city. In fact, the fast development of contemporary society of recent decades is leading urban environments to be ever more crucial nodes of the network of contemporary society itself. Human processes and transformations are concentrated in cities, where, since 2007, the majority of the world's population resides, where the natural environment is completely cleared to make way for the built environment and where the challenge of sustainability becomes more difficult, but essential. The "sustainable" city is the challenge of today, both in terms of local development, related to communities and local resources, and of global development related to society, energy resources, and the health of the planet.

Cities are connected by a dense and complex web of relationships and represent the heart and engine of the global development of contemporary society. But at the same time, cities are increasing their vulnerability. Catastrophic natural events can bring down cities and the network of relationships that take place in them. Natural events as extreme weather events (recently more frequent and intense as a result of the ongoing climate changes), earthquakes, tsunamis or man-induced events such as terrorist attacks or accidents, can have extreme effects on cities and communities. Hence, the resilience of cities against catastrophic events is a further challenge of today. City transformation processes must be rethought, to mitigate the effects of extreme events on the vital functions of cities and communities. Redundancy and robustness of the components of the urban fabric are essential to restore the full efficiency of the city vital functions after an extreme event has occurred. Hence, sustainability and resilience are the keywords for future cities.

It is widely discussed in scientific literature that sustainability and resilience are strongly connected. Numerous efforts have been made to theorize about the link between these two concepts applied to urban systems, to territories, or more generally to communities and thus to society. The UN Summit on Sustainable Development, in 2002, stressed the importance of including, within the framework of sustainability, the capacity of society to manage natural hazards and mitigate their impacts: "Can sustainable development along with the international instruments aiming at poverty reduction and environmental protection, be successful without taking into account the risk of natural hazards and their impacts? Can the planet afford to take the increasing costs and losses due to natural disasters? The short answer is, no." (World Commission on Environment and Development (WCED) 1987).

Callaghan and Colton (2008) stressed the need to build resilient and sustainable communities through the management of the community capital and its environmental, social, cultural and economic aspects. The community capital is the real engine of both sustainable development and resilience to extreme events. The concepts of sustainable development and resilience were also joined by Rose (2011) who theorized that the absence of economic resilience to violent changes induced by extreme events threaten sustainable development.

However the complexity in defining the relationship between the sustainable development of cities and the resilience of urban systems and communities against extreme events arises from the difficulty in defining singularly the concepts of sustainability and resilience. In fact, given their multidisciplinary nature, neither sustainability nor resilience present an univocal definition, but are open to different interpretations, depending on the point of view from which the problems are treated. In the following sections the different approaches available in literature to the definition of resilience and sustainability of cities are analyzed. Then a definition of city resilience against extreme events is proposed, strictly related to the concept of sustainability of contemporary cities.

5.2 Different Approaches to City Resilience

Today, extreme events, both natural and man-made, threaten cities more than ever, due to the high exposure of contemporary society in cities. Hence, city governments, anywhere in the world, need to implement risk mitigation and risk management actions, aiming at resilient cities against extreme events.

Historically, the concept of resilience was introduced first in the nineteenth century in physics, where it was used to indicate the ability of materials to withstand shock loads without suffering damages. Numerous definitions of resilience applied to urban systems are also available in literature and an excellent review is presented by Zhou et al. (2010). In fact, a contemporary city can be interpreted as a complex system, composed of dynamic relationships between its physical environment, i.e. infrastructures, space, networks and lifelines, the natural environment and its social environment, consisting of communities and their internal relationships. Hence, according to a general definition, cities can be considered resilient if able to cope with extreme events without suffering devastating losses and damages to their physical systems or reduced quality of life for the inhabitants (Godschalk 2003). However, a comprehensive definition is still not available, given the complexity in defining the properties of urban systems and the response of cities to extreme events.

What are the real operations taking place in urban systems? What about the dynamic equilibrium at the basis of the urban system operations? What is meant by limited damages and preservation of functionality for urban systems after extreme events? Does the optimal response of urban systems to extreme events, i.e. the "resilient" response, depend on the type of extreme event? These are just some of the questions that make the resilience concept exploding with different and multidisciplinary meanings, as proposed in literature.

Furthermore, the complexity of urban systems introduces a further distinction to the definition of resilience, depending on the point of view from which the problem is dealt. In applying the concept of resilience to complex systems, such as cities, two approaches can be followed: (a) the resilience of ecosystems, and (b) the engineering resilience. In the first, proposed and developed by Holling (1973, 1986, 2001), resilience can be defined as the ability of a system in dynamic equilibrium, subject to external shocks, to move to a different dynamic equilibrium stage. On the contrary, engineering resilience, developed by Pimm (1984), Bruneau et al. (2003) can be defined as the ability of a system to absorb an external shock and quickly return to the initial stage.

Apparently the first definition may be more complete and suitable for urban systems; in fact, moving from the fact that a complex system in dynamic equilibrium (as the urban system, which consists of physical and social subsystems linked by a dynamic network of relationships) can present different equilibrium stages (i.e. can "work") in various configurations, it can be concluded that a positive response to a malicious external shock can also be represented by a new equilibrium stage, different than the previous one. For example, looking at the terrorist attack on the World Trade Center in New York on 11 September 2001, it can be said that the city of New York had a "resilient" response. New York quickly recovered from the social and economic damages, even if the equilibrium was reached in a different configuration of the physical system, i.e. without rebuilding the World Trade Center towers and relocating the activities elsewhere. Furthermore, the social value of the towers, which had represented a crucial symbol for the collective identity of New York, has been preserved by reconfiguring the city in a different dynamic equilibrium; that place was re-though (i.e. Ground Zero). The towers' values still exist and their physical absence was recovered from the social and cultural point of view.

Nevertheless, engineering resilience is also extremely meaningful. In fact, one could argue that a complex and dynamic system, as the city, is always able to reach a state of equilibrium after a shock, because the ability of cities to adapt to changes is extremely high. But the new post-event dynamic equilibrium could be "worse" than the previous equilibrium stage; in this case only with an engineering resilience approach a "negative" response can be appreciated. Quality and performance indicators of the urban system can be used for this scope.

Thus, in order to merge the different approaches, it can be concluded that the urban system is resilient if, after the shock, it can reach a dynamic equilibrium stage, even if different from the previous one, but, at the same time, certain indicators of quality and performance of the system return to (or become higher than) pre-shock values. This concept was also introduced by Dalziell and

McManus (2004), which affirmed the need to introduce metrics of resilience. This approach can be strictly interrelated with the concept of sustainability metrics, discussed in the following section. Hence, given the need to introduce metrics of resilience, which indicators should be used? Are the indicators typically used to assess city sustainability suitable for the scope? Which quality and performance indices can describe the "effectiveness" of the response to external shocks?

The centrality of communities in urban systems presents an alternative conception of resilience. Rather than focusing on the strength and flexibility of built infrastructure, the social resilience of communities provides a buffer between the external shock and the individual citizen of an urban system (Adger 2000). Social resilience, according to Adger, can be measured by three characteristics: resistance to external shocks (a) the ability to recover from external shocks (b) and creativity (c), that is the ability to adapt to new circumstances. Hence, the approach to social resilience affirms the centrality of communities, able to manage the other physical elements and determine resilient urban systems.

In all the approaches so far analyzed, however, resilience is perceived as the ability of the city to have a "positive" response, when exposed to an external shock, as an extreme event. The main issue is the need to specify what a "positive" response is: the return to the previous equilibrium configuration or even a different reconfigured equilibrium stage? And, in a complex and dynamic system, as cities are, what is an equilibrium stage? Furthermore, is resilience to be reached separately both in the social and the physical system, or social system resilience entails physical system resilience? Thus, is the physical system resilience condensed in the community resilience? Hence, is community, representing the only decision maker for urban management, the only master of a city's destiny, the key to a resilient city?

5.3 Sustainability of Urban Systems

The concept of sustainability is used to define the optimal relationship between humankind and nature, in whatever form it may be realized. In fact, sustainability is required in all human processes involving the use of natural resources, the development of technologies and the development of cities and territories. However, the concept of sustainability is extremely complex and a successful deployment of sustainable processes can be extremely difficult. In fact, the sustainability of development aims to manage a complex system of individuals and entities, represented by citizens and society on one hand and by environment and natural resources on other, and linked through complex relationships and conflicts. Thus, a process or a transformation providing advantages to a group of individuals, can damage the environment or another group of individuals, near or far, in space and time, by interacting with the environment and natural resources (Gunderson and Holling 2002; Kates et al. 2001). Hence, only understanding and managing the relationships between individuals, society and nature a sustainable development can be pursued and implemented. The concept of sustainability can be divided into a set of concepts, representing the rules for sustainable development, as currently acknowledged:

- Sustainable development pursues both the present and future economic development of society, the welfare of individuals and the preservation of environment.
- Sustainable development meets the needs of present generations without compromising the ability of future generations to meet their needs.
- The rate of utilization of any resource must not exceed the rate of regeneration of the resource itself (Jansson 1984).

The concept of sustainability as here presented was outlined and defined in the eighties, as a result of a dialectical process initiated by a group of economists, led by Herman Daly and Robert Costanza. The first step was given in a symposium held in Stockholm in 1984, entitled "Integrating Ecology and Economics" (Jansson 1984). Tiezzi gave an original definition of the sustainable development issue, in his main work "tempi storici, tempi biologici" ("historical time, biological time") (Tiezzi 1984). He theorized that one of the main characteristics of contemporary society is the contrast between the fast pace of society and human transformations and the slow pace of biological cycles and nature transformations. According to Tiezzi, the reason for the environmental crisis is this conflict, which humankind has never faced in its history. Thus, according to Tiezzi, we need to reconsider the "biological time", pursuing the sustainability of any social and environmental transformation.

Using Tiezzi's approach, the onset of the conflict between society and nature times is highlighted in cities. Cities are the places where human transformations are condensed, where the natural environment is substituted for the built environment and the sustainability challenge becomes even more difficult to win, but essential. The "sustainable city" is the challenge of today.

Given these considerations, city sustainability should be pursued by analyzing and managing the effects of built environment transformations, in terms of economic, social and environmental impacts. In other words, city sustainability must represent a balance between the satisfaction, at different moments, of economic, environmental and social requirements, moved by different "city stakeholders", often conflicting with each other.

Hence, a generic city transformation is sustainable if it is:

- Equitable: satisfies social and economic requirements,
- Feasible: satisfies environmental and economic requirements,
- Bearable: satisfies environmental and social requirements.
- For a generic city transformation, the assessment of the satisfaction of these requirements provides an assessment of the sustainability.

5.4 Linking Resilience and Sustainability

In previous sections the concepts of resilience and sustainability applied to urban systems have been separately addressed. The link between sustainability and resilience of contemporary cities is evident and has been introduced by several authors, with different approaches but with a common objective. The UN Summit on Sustainable Development, in 2002, already mentioned above, emphasized that contemporary cities, in order to be sustainable, need to be resilient to disasters. In particular, Tobin (1999) tried to model the optimal city policy to be implemented in order to achieve sustainable and resilient communities. The proposed approach involves the use of 3 different models:

- mitigation models (a), i.e. the implementation of decision support systems aimed at engaging concrete actions to mitigate the risks;
- recovery models (b), i.e. systems of recovery operations from the post-event damaged configuration, to close the disaster-damage-repair-disaster loop; however the recovery operation system should not increase social inequalities and should take into account the complexity of the communities affected by disasters;
- structural and cognitive models (c), i.e. systems to make communities aware of the risks which they are prone to and to encourage them to implement even ordinary actions, to mitigate the effects of disasters.

By using this approach, Tobin defined the properties that resilient and sustainable communities should have. Moving from Tobin's approach the connection between the concepts of city resilience and city sustainability stays in the approach to the complexity of sustainability, in which resilience plays a fundamental role. In fact, as mentioned in previous sections, the complexity of sustainability can be summarized in the following rules:

- sustainability of a system involves a dynamic equilibrium between several factors related to economics, society and environment, often governed by different forces, contrasting each other;
- sustainability of transformations and processes must be pursued and ensured for all the time in which their effects propagate;
- sustainability must be pursued with reference to all the actors involved, both those directly participating to the processes and those affected by their indirect effects; furthermore, sustainability must be ensured for both the present actors and those belonging to future generations.

This approach to the complexity of sustainability is implemented in different scientific fields; for example, in engineering, a wide literature has been developed in recent years on indices, methods and procedures, for assessing the sustainability of products and industrial processes. According to these approaches, a sustainability assessment is composed by the following steps:

- For each man-made process and transformation, the social, environmental and economic impacts need to be evaluated.
- Furthermore, these impacts should be evaluated for the various actors involved in the process, that is, for example, in the case of an industrial product, workers, manufacturers, users, etc.

Therefore, these impacts should be quantified for the entire period in which the transformation process has effects, analyzing the impacts induced during the phase of production (a), use (b), maintenance (c) and disposal (d) phase, that is for the entire life cycle.

It is important to underline, since it will be useful hereafter, that some critical issues exist in the implementation of this approach:

- sustainability assessment can be conducted only once the boundary conditions, i.e. the unit to be analyzed, have been defined;
- sustainability assessment can only be comparative, between different options. In fact, each human transformation determines an environmental, economic and social burden; hence, sustainability assessment can only be aimed at assessing the "best" option, that is the less impacting one.

These recent approaches are also applied to the transformations of the built environment, where high environmental, economic and social burdens are induced. Hence, in these cases, since it is necessary to analyze the entire lifecycle of the urban transformations, all the potential extreme events that could hit the city structures and infrastructures during their life-time are to be taken into account. Hence, it is necessary to implement a probabilistic approach, as commonly used in risk engineering (e.g. multi-hazard loss estimation procedures), to deal with the possibility that different extreme events may occur on the physical elements of the city during their life-time. Thus, sustainability assessment should include the assessment of the resilience against the hazardous events, that is the sustainability of the post-event recovery processes. This phase can be named as hazardous event occurrence (HEO) phase.

5.5 Conclusions

Resilience and sustainability are now primary goals for future cities. On one hand, the extreme natural and man-made events that have recently hit urban systems, and on the other hand, the high environmental, social and economic burden that cities have today, combined with the high exposure of the world population in cities, make resilience and sustainability the main objectives for future development.

However, how the two concepts are linked and how we should imagine future cities in terms of resilience and sustainability, represent an issue for scientific debate. This work is part of this process and proposes an approach aimed at hinging the concept of resilience within the sustainability framework. The city is seen as a complex and dynamic organism, for which, as for any human process or transformation, sustainability should be ensured at each stage of the life cycle. The proposed approach moves from the point that, for the city, an extreme event and the resulting changes moving the city to a new point of dynamic equilibrium, represent a stage in the life cycle; hence, it is stated that resilience represents the sustainability of this phase, from the economic, social and environmental point of view, for all the present and future actors, directly and indirectly involved in the recovery process.

5.6 Recommendations

It can be stated that the sustainability assessment of any urban transformation must include a further phase within the life cycle, in addition to the construction, operation, maintenance and disposal phases; this phase is defined as that, whose impact are due to hazardous events that can take place in the life time and that can only be probabilistically treated. According to the current approach to sustainability, the effects to be considered for this phase are those due to the event occurrence itself (i.e. the direct damages and losses), together with the effects of the post-event recovery operations; furthermore all the effects must be evaluated in terms of economic, environmental and social burden, for all the actors involved.

Thus, the link between resilience and sustainability can be now clearly defined: in fact, a structure will be sustainable if, among other things, it is able to minimize the negative impacts of potential disasters, both during and after the events, in terms of social, environmental and economic burden, for all the actors involved; in other words, it will be sustainable if its HEO phase is sustainable, that is if it is resilient. In these terms, resilience becomes one of the characteristics that contribute to the sustainability. Raising the scale and looking at the entire city, the approach to sustainability assessment can be similarly defined; however, the concept of lifecycle must be redefined. Evidently, the city lifecycle, for our purposes, has no beginning and no end. Hence, the phases to be considered are:

- the phase of "use" of the city, or the city metabolism, which includes the system of activities and relationships that occur day by day between the different actors of the city and the day by day transformation of the physical system;
- the phase of "maintenance" of the city, or the city growing, which includes the activities for a continuous reconfiguration of the city, in particular of its physical system;
- the HEO phase, i.e. which includes the changes taking place when the city suffers an extreme event and tries to reconfigure both its physical and social system to reach a new equilibrium stage.

A city, or rather a configuration of the city, that is a configuration of its physical and social systems, will be more sustainable if it can guarantee economic, social and environmental benefits, for all its communities and for the future community, also during the HEO phase; hence, it will be more sustainable if it is more resilient. At this point it can be argued what is the correct approach to generally define the resilience of the city. Is it the engineering resilience, where it is expected that after an extreme event the city should return to the previous stage, or the ecosystem resilience, where it is allowed that the city can reach a dynamic equilibrium in a different stage?, the correct approach should overcome both ideas.

In fact, as a result of extreme events, cities undergo a system of transformations, which can be small or large and can affect its physical system and/or social system, leading to different possible equilibrium stages. Then, it is not helpful to debate whether resilience means the ability to return to the previous stage or reach a different stage of equilibrium. What is really important is to determine if the system of transformations, occurring during and after the event, is sustainable, regardless of the initial pre-event and final post-event equilibrium stages.

Specifically, since sustainability cannot assume an absolute value, it only makes sense to assess whether the system of transformations occurring after an extreme event is more or less sustainable than other options.

This approach clarifies how city resilience is a requisite for city sustainability and how the dichotomy between the ecosystem resilience of Holling (1973) and the engineering resilience of Pimm (1984) can be solved, when applied to urban system. In fact, the two contrasting principles that:

- a resilient response consists of a rapid reconfiguration in an equilibrium stage, even different from the previous one (ecosystem resilience), and
- a resilient response consists of a rapid recovery of the previous stage (engineering resilience),

are overcome by the principle that a resilient response consists of a sustainable response to external shocks; this implies that a different equilibrium stage can also be achieved (in terms of social and physical systems), but certain properties must be recovered, as the quality of life, the health of the environment or the robustness of the economic system.

A further crucial issue is represented by the definition of the geographical scale, used to evaluate the resilience of urban systems, i.e. to assess the sustainability of the HEO phase. Indeed, the complexity of contemporary cities stays in the network of relationships taking place within them, but also in the interlaced relationships that cities have with each other. The response of a city to an extreme event could be judged as not resilient, if referred to the single city resources and to transformations that its physical and social systems undergo. However, a resilient response, that is a sustainable HEO phase, may be based on the system of relationships that the city has with other cities; thus, the whole system of cities may have a resilient and sustainable response.

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