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► **To cite this version:**

Christine Voiron-Canicio, Giovanni Fusco. Knowledge challenges of the geopropective approach applied to territorial resilience.. Emmanuel Garbolino; Christine Voiron-Canicio. Ecosystems and Territorial Resilience. A Geopropective Approach., Elsevier, pp.57-84, 2021, 978-0-12-818215-4. 10.1016/B978-0-12-818215-4.00003-1 . hal-02975047

HAL Id: hal-02975047

<https://hal.science/hal-02975047>

Submitted on 6 Feb 2022

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Knowledge challenges of the geoprospective approach applied to territorial resilience

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3.1 Introduction

The future evolution of territorial systems, whether global or local, is a key issue for human societies, which these address with a variety of aims and from a variety of angles. This results in approaches that are specific to the chosen viewpoint. As we have seen, the

specificity of spatial prospective is to handle the issue while putting emphasis on the spatial point of view. The primary questioning underlying the geopropective approach concerns the way in which territories will behave when faced with the disruptions of a multiple nature that will occur in a not too distant future. How will they impact the territory, and in return, what will the latter's possible responses be depending on the changes?

In practice, this questioning breaks down into a multiplicity of scientific questions, and also practical ones, notably operational. Looking for answers to these questions is then done according to the methods determined by the goal to reach, but also by the theoretical and epistemological foundations on which the research is based (Mermet and Poux, 2002). Among these, the toolkits of system dynamics and of complexity theories, and the sustainable development paradigm, guide the reasoning process, and de facto, the lines of research, toward notions such as upholding on the long term, a system's adaptive capacity to changes in its environment to ensure its survival, and the forms of regulation used for achieving this.

These notions dovetail with resilience. Applied to territories, the latter can be understood in three possible manners: as a state, as a process, and as a property. The most frequent approach consists in detecting whether all or part of a territory has managed to hold on after a shock, and after diagnosing the state of resilience, in attempting to report on the process that generated it. The posture is a posteriori. Less widespread is the viewpoint considering that resilience existed prior to the shock and was revealed by the latter. Resilience is then considered as an intrinsic quality of the system, and research focuses on the resilience potential preexisting the shock. Here the posture is ex ante. Therefore the relation to time is different, and this has an influence on the way to conduct a geopropective approach. In the first case, the reactions observed in the past as a response to a type of shock will be used to infer the territory's future behavior, whereas in the second case, the future behavior will be assessed in accordance with the territory's adaptive potential. This second option is the most in line with the geopropective principles and is the one which we will mainly develop.

The focus will be on the systemic interpretation framework and the questionings it infers on territorial resilience. How to move from the theoretical frame of systemic resilience to the operational prospective framework? How does geopropective contribute to it? The potentialities of geopropective will be examined on two theme registers: anticipating territorial resilience to risk and the contribution of geopropective to the knowledge of urban resilience.

3.2 Territorial resilience through the systemic prism

3.2.1 Systemic resilience and complexity

The notion of resilience in system dynamics is different from the traditional sense issued from physics: the time of return to equilibrium for an object after a shock. The conceptual

base is the systemic resilience property. Indeed, the first quality of an open system is its adaptability to changes in its environment to ensure its survival when affected by a disruption. Thus ecologic resilience, as defined in Holling's seminal work (1973), is the ability of a system to absorb a disruption and to integrate it into its functioning while making changes but without altering its identity, its structure, and its essential functions. This reorganization, which is specific to living systems, is a system of permanent reorganization (Atlan, 1979).

From complex systems theory (Morin, 1974, 1990, 1994; Haken, 1977; Prigogine and Stengers, 1979), we will retain four fundamental notions which are as many keys to enter territorial systems and understand their behavior: complexity, adaptiveness, self-organization, and creativity.

The complexity and adaptiveness of systems are interrelated. The more complex behaviors are, the more they will show flexibility to adapt to the environment. They will be able to modify themselves in response to external changes—exceptional events, tensions—, and will also be able to alter the immediate environment, to adjust it, adapt it to their needs (Morin, 1974). Systemic complexity increases, on the one hand, with the growing number and increased diversity of elements, and, on the other hand, with the less and less determinist character of interrelations (Levin, 2002). Self-organization, which characterizes complex systems, makes them evolve in an unpredictable way toward various forms of organization. Their dynamics combine phases of stability and moments of instability during which changes, of course, can occur. These dynamics resulting either from an external disruption or from the amplification of small internal fluctuations play a role at the micro level.

Self-organization carries creativity within itself. It notably generates new forms and macrostructures which are not directly predictable from the knowledge of the states of microscopic elements (Pumain, 2003). This morphogenetic ability is not limited to genetic mutation, but also influences the system's behavior. The development of heuristic competences makes the system able to envisage several possible evolution strategies, to create conditions of choice. Thus the morphogenetic emergence is coupled with the emergence of degrees of freedom.

Furthermore, systems work at different levels of space, time, and social organization. Interscale interactions determine the system's dynamics whatever the scale considered. "The adaptive renewal cycles nested across scales have been termed panarchy" (Gunderson and Holling, 2002). Strong interscale relations are the very sign of the self-organization of complex systems and differentiate them from most systems, whether simple or complicated, which are only organized by their designers' external action (generally machines and technologies).

3.2.2 What lessons for the resilience of territories?

A territory seen through the systemic prism is an open sociospatial system with a high degree of complexity. Its complexity is due at the same time to its multicomposite structure—socioeconomic, environmental, spatial, and institutional components—, to the high number of these components, to overlapping scales and organization levels, as well as to interrelations of various natures with the environment, notably through information and via the remote influence of exogenous variables.

Territories are sociospatial systems and can be distinguished from ecosystems by two specificities. On the one hand, change is driven by invention-innovation, which does not come from the natural environment but is consubstantial to sociotechnical systems (Holling and Sanderson, 1996). Permanent invention-innovation enables territorial systems to develop new organizational arrangements much faster than ecosystems do, that is, over historical times. On the other hand, the momentum of change is impelled by cognition. Representations, information, memory, and learning have an influence on decision-making, with more or less awareness, and introduce anticipation and strategy in the way systems operate. The perception that stakeholders have of their territory affects its evolution. The self-fulfilling prophecies which partly guide social evolution are an extreme case of the foregoing (Pumain, 2003).

A territorial system, like an ecologic system, evolves according to a cyclic transformation process formalized by Holling as the “adaptive renewal cycles”—growth, collapse, reorganization, renewal, and reestablishment. The change of a territorial system will be dependent on the way it reacts to disruptions of various origins and natures. These come either from the external environment—natural hazard, technological disruption, political or economic crisis—or from internal phenomena generated by the way the territorial system works—population aging, specialization in an activity, land artificialization. These slow or sudden disruptions continuously affecting the system are the reason for its variability. Either the system adapts by integrating the disruption into its functioning by means of adjustments or it resists and the existing structure may be reinforced in order to counter the disruption’s negative effects. Adaptation reflects a degree of flexibility in the system’s functioning whereas resistance strategies rather show some rigidification.

The spatial systems, in constant evolution, are very seldom in equilibrium, and for a short period. This has two fundamental implications. On the one hand, a system characterized by high variability will have more chances than a system with high stability to put up with a disruption without collapsing, because it will be more flexible and more able to incorporate it into its functioning (Aschan-Leygonie, 2000). On the other hand, this variability induces the possibility of, and therefore, various trajectories which are possible responses to a disruption as well as organizational solutions such as the appearance or disappearance of territorial subsystems.

The theoretical framework of adaptive systems and also the research applied to sociospatial systems bring out two categories of resilience criteria, one linked to the territorial system—spatiotemporal variability of its characteristics, level of robustness and adaptivity—, the other linked to the disruption—nature, extent, sudden appearance vs gradual. Nevertheless, the same research works warn against generalizing these criteria and against a deterministic vision of their effect. Geographic, historical, and organizational territorial contexts in which these criteria occur play a major role and explain the different impacts on resilience that can be observed from a territory to another. Moreover, the ways in which the system reacts to a disruption, the bifurcations and emerging structures which they generate make the evolution of a territorial system unforeseeable, and de facto, unpredictable. From then on, how to anticipate its future? What should be the targets of a prospective analysis?

The systemic reasoning leads to new questionings on how territories function and on their spatiotemporal trajectory, which guides the prospective approach toward research questions where resilience and future evolution of territorial systems are closely interrelated.

3.3 New questionings

3.3.1 Going deeper into the relation between territorial sustainability and resilience

The concept of territorial resilience is related to the paradigm of sustainable development, of which it is one of the dimensions. Despite recommendations issued at world summits in the years 1990s, the beginning of the years 2000s has undermined the fundamental principles of transversality and adaptation intrinsic to sustainable development. Of the three parts of sustainable development, the environment tends nowadays to prevail in sectorial public policies, so much so that sustainable development is often confused with the environment (Voiron-Canicio, 2015). Another confusion adds to it, this time with the economy of resources. The environment is often reduced to the minimalist vision of a municipality's environmental performance (Rumpala, 2003). However, a return to the original conception of sustainable development took place recently. As an example, at the Conference on Housing and Sustainable Urban Development (UN Habitat III) held in Quito in 2016, the new urban agenda clearly interrelated resilience and sustainability, by defining the ideal sustainable city as more inclusive, safer, more resilient, and fairer. To this resilient structure is associated concerted development as the harmonization variable of sustainable development (Da Cunha and Thomas, 2017).

Furthermore, at the beginning of the years 2000s, research on resilience gave new impetus to sustainability science, an emerging field of research “that seeks to understand the fundamental character of interactions between nature and society and to encourage those interactions along more sustainable trajectories” (Kates et al., 2001; Clark and Dickson, 2003; Independent Group of Scientists, 2019). In this new context, the fight against climate

change is seen as an opportunity to implement sustainable development, the aim of which is not only to slow down climate changes but also to allow the survival of ecosystems and human societies (Magnan, 2009). Improving the resilience of a territory appears as a means of increasing the chances to come close to the objectives of sustainable development (Folke et al., 2002; Da Cunha and Thomas, 2017; Scherrer, 2017). “Sustainability is viewed as a process, rather than an end-product, a dynamic process that requires adaptive capacity in resilient social–ecological systems to deal with change” (Berkes et al., 2003). From then on, the hybridization process that takes place between resilience and sustainable development has to be analyzed. As far as public action is concerned, does resilience help to operationalize the utopian vision of sustainable development? Is it the path to follow to move toward sustainable territorial development, and how?

3.3.2 Reexamining the link between resilience, adaptation, and adaptivity

The question of a territory’s resilience has first been studied in the context of natural or technological risk, and mainly from the technical-functional viewpoint—performance of protective structures, reducing the vulnerability of technical networks, constructing new resilient buildings. The current research questions relate to the evaluation of stakeholders’ ability to imagine and anticipate disruptions likely to affect a territory. The challenge is twofold; on the one hand, examining a territory’s learning capacity based on feedbacks on past events and more globally on collective memory, and on the other hand, working out evaluation methods of adaptive capacity.

Faced with a disruption, the response of the territorial system’s stakeholders can be to resist, give up, or adapt, and the adaptation of a territorial system to an exceptional event generally combines all three behaviors, which occur either simultaneously or successively. A territorial system’s resilience at a given moment results from that complex combinatory. However, interrelations between adaptation and resilience need to be defined better. In fact, the two notions are often confused. What differences can be identified between the mechanisms of resilience and those of adaptation? If adaptation and resilience are complementary, how to express it in strategies and actions? More globally, what does adapting mean for a territory? What to adapt to, when and where? (Magnan, 2010).

Adaptation is usually understood according to three perspectives, as a process, a state, or a strategy, and most of the time, separately. Nowadays, research on their articulation is needed to define trajectories of adaptation so as to help work out resilience strategies (Fig. 3.1).

Furthermore, it is indispensable to acquire further knowledge about the determinants of a territory’s adaptive capacity, and about adaptation modes—reactive vs anticipative—in order to better take into account the complexity of the adaptive process, and thus avoid to

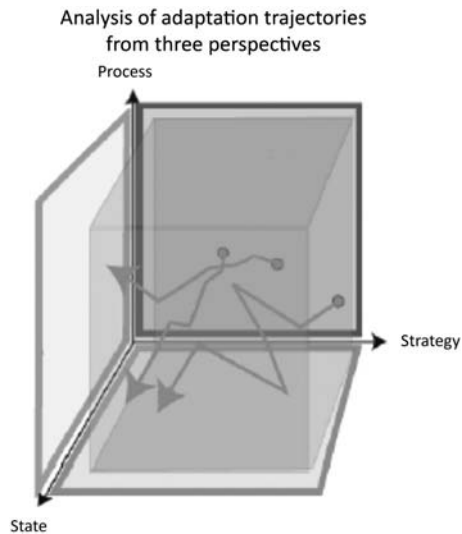


Figure 3.1 - Understanding adaptation trajectories by interconnecting three perspectives: state, process and strategy.

reduce the adaptive capacity to a strictly economic and technological vision, or to link, in a determinist manner, level of development and capacity to adapt to climate change (Smit et al., 1999; Smit and Wandel, 2006; Vincent, 2007; Adger et al., 2009). Likewise, the factors affecting the adaptive capacity do not act individually, but interact by generating synergies or, on the contrary, negative retroactions. Alexandre Magnan suggests handling these various issues by coupling them in a research framework aimed at assessing a territory's adaptive capacity to climate change (Magnan, 2009). He identifies four main lines of research to deepen the understanding of adaptive capacity: factors influencing adaptive capacity, the spatial and temporal scales that are relevant for adaptation, the relationship between vulnerability and adaptive capacity, and the link between adaptation and sustainable development. More precisely, he invites researchers to identify the thresholds beyond which the positive effects of a given adaptive factor—territorial cohesion, network structuring, economic diversification, etc.—fade out, and can even be reversed.

Today there is some consensus on the structural, organizational, sociocultural, and technical conditions that contribute to reinforcing a territory's resilience, and enable it to face an exceptional situation, whatever its origin (UNISDR, 2012; Laganier, 2013; Giacometti and Teräs, 2019). Territories are characterized by their different capacity to bring together these favorable conditions in order to improve resilience: capabilities of resistance, of collective response, of self-organization, of learning, and of adapting. Among these capacities, the

OECD singles out three major ones: the absorptive capacity—the ability to resist the negative impact of shocks; the adaptive capacity—the ability to adapt to new conditions; and the transformative capacity—the ability to change fundamental structures (OECD, 2014). Ongoing research endeavors to detect these capacities in various geographic contexts. However, the focus is mainly on political, socioeconomic, and cultural factors. But the spatial dimension of resilience is still relatively unexplored.

3.3.3 Going deeper into the role of the spatial dimension in resilience

3.3.3.1 Space and resilience of systems

Space is essential in any resilient system. It is not just a matter of identifying the portion of space occupied by various elements or of understanding how a more or less long distance can have an effect on certain phenomena, but of seeing how a system's spatial structure, that is, the more or less stable organization of its elements and functioning in space, offers many possibilities or constraints to the system's possible adaptations and transformations faced with a changing environment.

The theory of the general resilience of ecosystems proposed by Holling finds an essential complement in the concept of spatial resilience. For Cumming (2011) it underlines the role of the spatial dimension in ecosystems. Spatial resilience concerns the way in which the spatial variation of key variables, both inside and outside the system, influences (and is influenced by) the system's overall resilience through the multiple spatiotemporal scales. Trans-scale properties, just like the factors of form of ecosystems (connections by corridors, extension/density/fragmentation of habitats, etc.), come back at the center of the mechanisms through which an ecosystem is capable of showing resilience, beyond the sole diversity of the species that are present.

It is clear that analyzing the resilience of a spatial system is closely linked to the specificities of the system being studied. Beyond a few principle analogies, the spatiality of an ecosystem is not the same as that of a city, a wine-growing region, or a transnational industrial system. The theory of complex systems can thus provide a common framework for reflection, but it would not be easily operational to evaluate the resilience of specific spatial systems. In the last section of this chapter, we will expound a spatial resilience theory specific to evaluating the resilience of the city's forms and how this theory could contribute to informing an urban geopropective. A similar effort will be required in every area of the territorial analysis, to identify every time what are the elements of the system's spatiality which are most important in terms of resilience and how recognizing more or less resilient spatial structures in the present system and in the different scenarios can help to choose a shared benchmark scenario. Nonetheless, in what follows we are going to present some key principles of the role of spatial organization in systems change, regardless of the field of study.

3.3.3.2 Interactions of spatial structures and change

The role of spatial interactions on the modes of change and, consequently, on the resilience of territorial systems should be identified better. Interactions are of two kinds: one horizontal, between places and elements located at variable distances; the other vertical, concerning the links between society, space, and the environment. The two interactions combine in the way the system confronts a disruption. Until now, research focused mainly on vertical interactions between the human society and ecosystems (Aschan-Leygonie, 2000). What is still needed is a deeper understanding of interactions between spatial structure and change and, by extension, of resilience.

In this perspective, stimulating avenues of thought are provided by the works of environmental scientists and those of physicists. Environmental scientists working on spatial patterns have since long observed the role of the components' spatial configuration in the resilience processes of species (Scheffer and Carpenter, 2003; Scheffer et al., 2012; Rietkerk et al., 2004). For their part, researches carried out by physicists on the robustness of networks have highlighted the importance of connexity in the vulnerability of scale-free networks and in the transmission of domino effects (Barabasi and Reka, 1999; Barabasi, 2002). Studies of the behavior of complex systems converge on the crucial role played by two structural characteristics, heterogeneousness and connectivity, in the response of a system to a change in its environment. For example, it has been observed that components' heterogeneousness combined with a low level of connectivity tends to produce a gradual change. Conversely, spatial homogeneousness and a strongly connected network tend to foster resistance to change up to a certain threshold beyond which all components swing synchronously to another state. However, in the face of the change which continuously impacts the spatial structure of territorial systems, interactions between the structure of the built-up area, for example, and its function—its uses—take various forms. The spatial structure can remain unchanged whereas the function has changed, or the spatial structure can be modified even though the use by stakeholders has not changed.

Determining the role of spatial structures and dynamics in a territory's resilience process is a research goal which fully concerns geoproerspective. Because of the diversity of its methods, the latter enables researchers to question in many different ways the relationship between spatial change and the behavior of territories vis-à-vis the pressures exerted on them.

3.4 Spatial change and resilience seen through the prism of geoproerspective

One of the entries into the issue of resilience consists in examining the mechanisms of spatial change from various angles: the territory's propensity to change, anticipating future changes, and its adaptive potential.

To do so, two main avenues open to researchers: to analyze the territorial system's trajectory and to anticipate its response to future tensions or crises, focusing on the system, not the risk. These approaches come under spatial prospective.

Researching the spatiotemporal trajectory and adaptive potential enables researchers to consider the evolutive character of adaptation. Indeed, the global and local context is continuously changing, the territory's adaptive capacity evolves as a result of previous choices—political decisions, action undertaken vs inaction. Therefore the adaptive capacity at a moment T is no guarantor of the capacity at the moment $T + 1$. Then, it must be constantly reconsidered in the light of simultaneous changes of the territorial system and its environment, which makes the task much more complex. So, rather than researching the real ability to adapt, it seems more relevant to assess this evolutionary process through the spatiotemporal trajectories of response to the forces of change and to adaptation to change in relation to a dynamic vision of the territorial functioning (Magnan, 2009; Voiron-Cancio, 2012).

3.4.1 Spatiotemporal trajectory and propensity to change

Although spatial change is not predictable, the territory's propensity to change can be examined in the light of the past trajectory. The aim is not to extrapolate the trend observed in the past but to identify the process of spatial change, to characterize the behavior of the spatial components under the pressure forces—demography, land speculation, climate constraint, etc.—exerted over time. The important here is not the nature of responses, but the form of reactivity of each spatial component in the overall spatiotemporal trajectory. The dynamics of change over a period is assessed qualitatively, using the spatial change index which synthesizes the behavior of the various components in the timeline: indices of similarity, turnover, diversity, intensity, quality, and speed. For example, the turnover index records how many changes occurred between adjacent pairs of years (Swetnam, 2007; Casanova, 2010). The spatiotemporal trajectory can be characterized even more accurately, as shown in the research carried out by Sophie Lizard (2013) on the prospective of the Latin Arc's littoralization. This author has worked out indicators that inform on the preferred direction that population movements could take in the future. Other indicators inform on the instability of the past trajectory, on changes of direction or temporary standstills, the stage of the densification process in each subspace—early, intermediate, advanced—and how fast the population grows. All the information provided by these indicators can be combined in order to identify stake-laden spaces: saturated spaces, those near saturation, and potential spaces for densification transfer (Lizard, 2013).

These spatial prospective analyses provide a knowledge on the spatial process of change. The qualitative information drawn from the past trajectory in no way prejudices the future trajectory but makes it possible to assess the spatial dimension of the territory's

responsiveness. It helps to identify the potentials of spatial change, not for predictive purposes but as an aid for working out scenarios for the future.

3.4.2 Anticipating the early-warning signs of change

A disruption external to the system—rising sea levels, for example—or an endogenous phenomenon such as the deterioration of electrical infrastructures, creeps in progressively, slowly and continuously, until a disaster or a crisis occurs suddenly—submergence of a coastal area, power blackout—, which makes people aware of the connection between the exceptional event and its root causes.

Bearing in mind that the dynamics of change operate both with gradual signs and more sudden ones, it is useful to look for the early signs of sudden changes. This new field of research aims to determine the generic early-warning signals of a sudden change, and even of a critical point affecting ecosystems, also concerns sociosystems. The ongoing research aims notably at discovering the pertinent indicators of an approaching sudden change

(Scheffer et al., 2009). A number of signs deserve attention: changes in spatial configuration, a recovery rate after an exceptional event tending to decrease with the passing time, a phenomenon described as “critical slowing-down,” an increase in the system’s variability, a sign that the system explores a wider variety of states, the temporal monitoring of a variable characteristic of the ecosystem—biomass, vegetation cover, etc.— that shows an increase in variance, a strong autocorrelation, and temporal asymmetry are signs considered as temporal indicators of an approaching sudden change, and even of a critical point. Recently, studies have shown that the equivalents of these indicators—spatial variance, spatial autocorrelation, spatial asymmetry-, —are characteristic of a spatial system evolving toward sudden change (Dakos et al., 2009).

3.4.3 Anticipating the occurrence of tensions through anticipative monitoring

Another challenge consists in anticipating risk-bearing future tensions. It is no longer a matter of analyzing the past trajectory, but of detecting, in the present, weak signals of the future, via anticipative monitoring. The concept of anticipative monitoring implies to project oneself into a future which is not only probable in the light of the recent past, but equally plausible, or even merely possible. There is a dual objective: detecting situations likely to create tensions in the functioning of all or part of the territory, which could lead to new vulnerabilities, and assess the overall resilience capacity of the territorial system. This second objective is not easy to reach. However, exploring the future can be envisaged. The research posture requires to look for antagonistic forces in preparation or likely to occur and create tensions and for new risks. For example, the emergence of a technology elsewhere is a risk for a region of traditional industry, but is also an opportunity if the territorial system is reactive, and capable of transforming the shock into a creative

disturbance by provoking knowledge spillover and diversification. The posture consists in broadening the field of vision in order to perceive the global–local interactions and, more precisely in

- Paying attention to concomitant phenomena yet that play on different temporalities, to delays before the effects of public policies and local developments are felt. For example, a local policy in favor of carbon-free mobility—incentives to buy electric cars, opening of new electric tram lines, etc.—requires that the regional power supply be secured beforehand, either by completing power infrastructures guaranteeing a stable electricity supply or by rolling out charging stations in smart-charging mode enabling the electric vehicle’s battery to give energy back to the grid at peak demand.
- Detecting weak signals. A weak signal is a furtive information, seemingly innocuous, fragmentary, with no apparent utility, equivocal, uncertain, etc. (Lesca, and Lesca, 2011). Picking it up necessitates to be on the alert but without a definite objective or theme, and receptive to information coming from various sources. Once it has been picked up, the weak signal must quickly be put together with other pieces of information for cross-checking. The interpretation is carried out collectively by comparing various opinions. The weak signal is a key element of geopropective. It constitutes not only a point of vigilance, but also a basis for scenario building.
- Looking for opposing forces in the making or likely to occur and cause tensions, for risks and the resulting new vulnerabilities, as much human as material and organizational. An emerging technology elsewhere can be a risk, but is also an opportunity, a creative disturbance by provoking knowledge spillover and diversification.
- Detecting differentiated dynamics in space, the places conducive to technological innovations, those creating collective innovations, and a contrario, spaces losing momentum (Voiron-Canicio, 2013).

3.4.4 Detecting a territory’s adaptive capacity

A territory’s adaptive capacity is the cornerstone of the resilience process. Geopropective provides a range of tools to help detect, within a region or a city, elements that contribute to forging that capacity. The expression “adaptive capacity” encompasses the abilities of the various local actors to anticipate the forces of change, detect their impact on the territory, and act to prepare the latter to face it. Such anticipation, as we just saw, is achieved through anticipative monitoring. It is also achieved through researching the exogenous risk-bearing trends but also opportunities for the territory being studied and through analyzing the endogenous stressors, that is, the long-term trends that weaken the potential of a region and deepen the vulnerability of its actors (OECD, 2014). This capacity rests greatly on human competences, and more precisely on awareness, readiness to change, and the

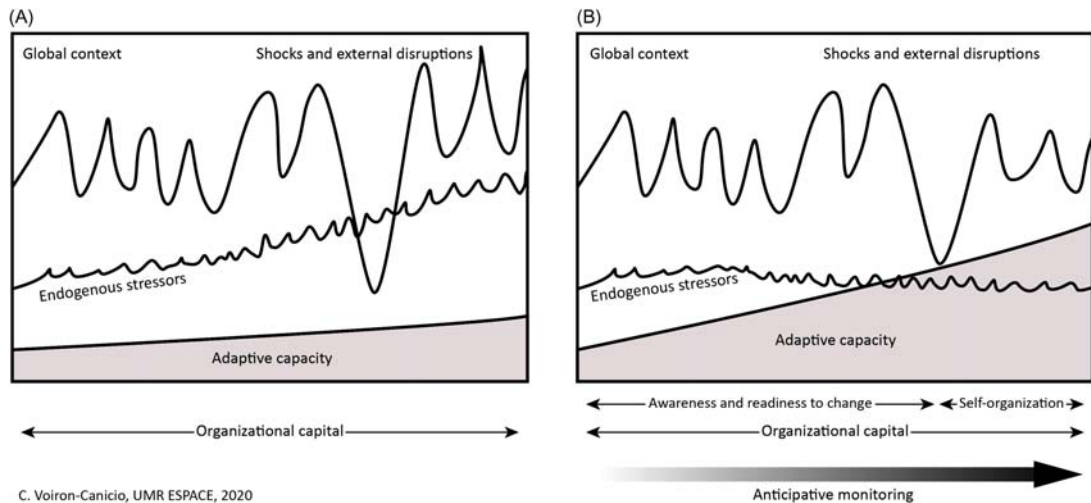


Figure 3.2 - Relationship between adaptive capacity to shocks/stressors and organizational capital: (A) weak organizational capital and (B) strengthened organizational capital.

organizational capital. We saw in Section 2 that adaptive capacity does not exist in the absolute that the factors influencing it do not act in isolation but in a systemic way. This capacity is peculiar to each region and specific to its physical and human context (Fig. 3.2).

Therefore the first task is to detect, in the regional system, the various elements that scientists and planning experts agree to consider as favorable to adaptation, or on the contrary, unfavorable. Studies on the resilience of biological systems highlight diversity, connectivity, redundancy, and multiscale interconnections as criteria contributing to adaptability and mutability. All these structural features can be detected easily within a region by spatial analysis. Processing will focus on the organization of space, the structure of internal and external relations, the configuration of networks as well as the degree of functional diversification—activities, businesses, employment—, and also spatial—presence of subregions and intensity of their interactions. However, for all that, high values on these criteria do not lead to a high adaptive capacity. Furthermore, the role of these criteria in the adaptive capacity's construction process remains uncertain, and even controversial at times—the diversity of stakeholders in a quick response to a crisis, for example. On the other hand, there is more certainty on the detrimental effect of a number of elements, such as run-down communication infrastructures, relative isolation, and a low-education population. These weaknesses and constraints are undoubtedly brakes on recovery after a crisis. Over-dependence on a sector, aging population, demographic decline, skills shortages, unreliable transportation, changing climate conditions, etc., are slow burns that reinforce other stressors in a series of negative feedback loops. Here, reasoning using the

via negativa (Taleb, 2012) by focusing the attention on endogenous stressors which constitute real handicaps proves more pertinent. This analysis should be complemented by looking for information on the behavior of local actors. Regarding the population, it will be useful to gather qualitative information coming from surveys, for example, on the attachment to the region, the trust in local institutions, and in the absence of surveys, to scrutinize the rate of youth emigration, notably in a crisis period. Regarding stakeholders, information on the existence of collaborative culture among regional actors and of inclusive governance practices will be favorable signs for self-organization, which is necessary to absorb change by reorganizing work and partnerships and reevaluating strategies (Giacometti and Teräs, 2019; Adger et al., 2005).

Processing this spatialized information using spatial analysis tools and mapping it will result in a detailed knowledge, combining new quantitative and qualitative information that no standard database can provide on the regional system. Then, the second task consists in gathering and organizing this multiform knowledge within a knowledge base synthesizing the elements that are essential to understanding the forces specific to the region being studied. These forces, both established and latent, are potential engines for adapting to still unknown future events. Geoprospective modeling, and more precisely building scenarios of possible futures, draws on this knowledge base.

3.4.5 Anticipating the functioning of a territory on the long term using simulation

Geoprospective simulation is a valuable aid for exploring the future and evaluating the reactivity of a territory faced with pressures to come. The following example illustrates its importance. The purpose of the model is to examine what could be the impacts of CC on the functioning of an urbanized territory, which otherwise is evolving according to its own socioeconomic dynamics. Usually, the chain reactions that occur on the short term but also the lasting repercussions on the system's structure and dynamics are not well defined. An example of geoprospective modeling applied to this problem is the SERENICIM prototype. The aim of this program is to help anticipate the impacts of climate change on the functioning of a Mediterranean urban area (Voiron-Canicio et al., 2009). The SERENICIM model has been worked out by using the Nice agglomeration as a test. This region is a particularly complex urban system because of interacting environmental and anthropic dynamics, and the conflicts of use between property, tourism, peri-urban agriculture, and the industrial-commercial activity, all of which unfold on an ever scarcer space. In its current version, the systemic model simulates the functioning of the territory by creating interactions between the progressive changes—quarterly lag until 2050—of the local climate's physical parameters—temperatures, rainfalls, seasonal variability, extreme events—and the urban anthroposystem of which the structure is made up of six components: the resident population, numbers of tourists, land use, water resources, water

consumption depending on the type of habitat, and the type of agriculture. The energy component is currently being introduced into the system. The territory's dynamics is modeled using a system dynamics model—stock-flux model—where interactions between the system's components are expressed by circular causal relations and either positive or negative feedback loops, which give a clear picture of the complexity of interactions otherwise difficult to perceive. The resilience of the system is assessed by analyzing the behavior of the territorial system in a context of progressive climate change, interspersed with crisis episodes due to climate paroxysms (torrential rain, marine incursion, drought, heatwave). The future risk of water shortage is yet ill-defined in urban territories, notably in the Mediterranean region. Measures taken by the authorities are of the crisis management type, by means of water restrictions bylaws, based on alert thresholds. The purpose of the simulations is to assess the impacts of such measures in the case of water shortage risk. Drought spells have been introduced randomly in the course of the simulation period. The model includes alert thresholds concerning water resources, which trigger various kinds of water consumption restrictions for domestic and farming use. Then simulations make it possible to assess the effectiveness of measures adopted in times of crisis, and their long-term effects, and more precisely, to observe whether agricultural activities remain viable with the measures adopted. It then appeared that frequent water consumption restrictions had, on the medium term, significant impacts on peri-urban irrigated agriculture, already weakened by urban pressure. The simulation exercise of drought periods combined with public action revealed that water restrictions—an emergency response to an existing or imminent water shortage—is not the best strategy for the overall resilience of the urban area on the long term. With the idea of preserving urban agriculture, this geopropective exercise impels the territory's decision-makers and managers to establish, as from now, a water governance policy with all stakeholders, and more particularly with farmers, to think about a transition toward new farming methods that would be viable both on the short and long terms.

3.5 Resilience of forms and urban geopropective

In this section, we are going to show another area in which the issue of resilience becomes central in urban geopropective. To remain very close to the challenges of planning, the question will be mainly about the resilience of the city's physical forms, on which urbanism usually intervenes. Therefore we will talk mainly about the city's morphological resilience (Fusco, 2018), a viewpoint which should clearly be complemented by the resilience of human capital, of the system of governance and, more broadly, of the city's social fabric. At the same time, the physical forms make the city's spatiality a central issue, thus going beyond the mere framework of a strategic prospective that is projected on a territory but does not identify the constraints and potentials of its spatial organization.

3.5.1 From the controllable city to the complex city

Spurred on by metropolization processes and sociotechnical change, the city is undergoing accelerated transformation (Ascher, 1995; Newman and Kenworthy, 1998; Wiel, 1999; Bourdin, 2014). The city is being built differently, integrates new urban objects, is breaking up and spreading, new centralities are emerging, techno-eco-neighborhoods are produced on models that are becoming globalized, and at the same time, entire neighborhoods and sectors are collapsing, productive and commercial fabrics are declining, and urban landscapes are disappearing. These transformations raise new challenges of sustainability: to the usual issues of urban pollutions, consumption of resources and economic and social development add more existential challenges such as the places' identity, the dialectic between heritage and globalization, solidarities between the metropolitan components, and the risk of accelerated obsolescence of the new forms of urbanization faced with the constant turnover of sociotechnical functioning.

Both the geographic theories and the practice of planning and urbanism are challenged by the new functioning of urban and metropolitan areas and the associated physical forms. The need of new geographic knowledge of the city is emerging to understand its most recent transformations and provide guidelines for envisaging its future.

Scientific paradigms are also changing. Traditionally, geographers and planners were looking for "strong" theories to explain urban phenomena and foresee their unfolding, both in time and in space. On these bases, rational comprehensive planning (Mc Loughlin, 1969; Faludi, 1986; Taylor, 1998; Portugali, 2000) focused on land use and resource allocation. Its forecasting and optimization procedures left no room for uncertainties. Its functionalist vision of the urban space was also indifferent to form issues: the important thing was to regulate the quantity of urban functions and their location, giving free rein to the designers of urban forms (developers, architects, public operators), by crossing building standards, traffic requirements, and the trends of the time. Garden cities, modern cities, and postmodern complexes followed one another in time and juxtaposed in space. Their urbanistic performance has rarely been assessed a posteriori. Furthermore, no urban prospective exercise conducted before the turn of sustainable development in the years 1990s broaches the issue of the forms of urbanization. The common practice regarding urban prospective was using demographic, transport, and land-use models, to justify urban development plans, regulatory zoning plans, and local housing programs.

Echoing what we have seen in Section 1, the framework in which the scientific community nowadays repositions the knowledge of cities and their physical form is that of complexity science. The city is a complex system characterized by a dialectic between self-organization tendencies and attempts of control, which are always partial, by plans and policies. But the knowledge that we can have of such a type of system is always incomplete, approximative,

and uncertain. The uncertainty of knowledge and the nonpredictability of future states are one of the major challenges to move from the “controllable city” to the “complex city.”

3.5.2 Implications for planning and the need of a geopropective approach

The imperfect knowledge of the complex city (Portugali, 2000; Marshall, 2012) shakes up the traditional approaches to planning and urbanism. In economics, Hayek (1967, 1978) had already made the case that, for a complex social system, we cannot obtain “detailed” knowledge (explanatory or predictive), but only knowledge “in principle,” enabling us to sketch the system’s typical behaviors qualitatively. As far as urban planning is concerned, Moroni (2015) and also Alfasi and Portugali (2007) suggest to give up producing plans based on forecasting and let urban self-organization emerge within a system of simple rules. In fact, knowledge is already injected into any rule system. As an example, Talen (2012) shows that rules are not neutral and that the making of the city could give a much larger part to urban codes as compared with set plans, mass layout, or zoning plans. Using codes and a few key principles on the urban forms being sought would be much more likely to foster urban self-organization, because it would allow more flexibility to the making of the city. But what role should we give to projects and plans in such context? Two other questions, even more existential, arise when thinking about the future of the city, justifying possible plans and projects, but also any decision concerning a set of codes to impose to urban stakeholders. First, can we base a vision of the city’s future on weak and nonpredictive theories? Next, is there a theory of the complex urban form and how could it inform this vision of the city’s future?

According to Bleic and Cecchini (2016), in the context of planning and urbanism, the answer to the first question is clearly positive. The vision of the future is even necessary. By admitting that the future is not predetermined by a strong theory, but that different futures remain possible, it becomes essential to mobilize the energies of urban stakeholders to give a meaning and legitimacy to the collective action and, at the same time, create the best conditions to attain the future which has been consensually identified as desirable. The tool enabling to make the desired future explicit is the project, and the approach to achieve it is, for these authors, a prospective approach, and more precisely, a geopropective one. The absence of strong theories undermines also the technocratic approaches to the project, where scientific knowledge was formerly imposed to stakeholders in a top-down manner, and reinforces the importance of the shared project. The project will probably be more flexible and will take the form of strategic geopropective, so as to coordinate the actions of individual stakeholders in the urban self-organization.

Dupuy (1992, 2012) provides theoretical bases to the necessity of both project and prospective: the characteristic of sociotechnical systems is the possible retroaction by the future (see also Section 1.2). If the stakeholders coordinate themselves in view of pursuing

a shared project, the said project, which does not yet exist as a state (future in any case) of the system, is capable to interact with the current state and the dynamics at work to modify the course of events (without any guarantee that the system's future state will be that recommended by the project, of course).

However, the absence of strong theories and the fact that technocratic approaches are left out do not mean that the new scientific knowledge should not play a part in the working out of this shared vision. Indeed, scientific research in geography and urbanism, in connection with advances in complexity science, has produced in recent years an increasingly clearer vision of the role of form and spatial organization in the complex city. Traditionally, the city's strategic prospective paid little attention to the spatial dimension's potentialities and constraints and, in particular, to urban forms. Nowadays, the shared project can be produced within an urban geopropective approach rooted in the specificities of the complex city, of the spatial logics of its physical forms, with their constraints and potentials, and be informed about the uncertainties of our knowledge of urban futures (Fusco, 2018). The aim of urban geopropective is to explore the complex city's possible futures, in order to lay the foundations of an effort of collective organization in an irreducibly uncertain context. The contribution of the new scientific insights could then precisely be as follows. Scientists are neither in a position to provide a foresight of the urban future, nor to identify the universe of possibilities with certainty. However, they can help identify the forces and weaknesses of the existing city and of the outlines of the proposed projects (the shared vision).

3.5.3 Resilience as a response to unknowable futures

In this context of profound uncertainty on urban futures, a consensus seems to be emerging today on the opportunity to achieve highly resilient and so-called "antifragile" urban forms, capable of adapting and changing to benefit from the sociotechnical innovation constantly produced by the city (Holling and Sanderson, 1996; Pumain, 2012; see Section 1.1). If the concept of resilience is derived from already mentioned seminal works in ecology, that of antifragility, first proposed to the general public by Taleb (2012), was soon used in urbanism and planning (Blecic and Cecchini, 2016). From our point of view, antifragility can be seen as a highly adaptive and transformative form of resilience. In any case, regarding the resilience of urban forms when faced with sociotechnical change, the posture toward resilience will essentially be *ex ante* (Section 1.1): it is a matter of identifying the resilience potential of the city's forms, observable or projected, guided by a theoretical approach to morphologic resilience.

A first theory of the resilience of urban forms is based on the configuration of street networks (Hillier and Hanson, 1984; Hillier, 1996; Marshall, 2012), of which the best-known protocols are those of space syntax. This approach appears directly in a geocomputation context and specifies to urban spaces the protocols for analyzing complex

networks (Freeman, 1979; Barabasi, 2002). The configurational approach shows that the founding principle of urban organization is not distance in itself, whatever its definition, but the system of the whole of reciprocal distances, that is, the configuration. The configurational properties are emerging and strongly structure the potential of urban spaces. Hillier (1996) identifies the configuration of street networks as a major interface of the city's socioeconomic functioning. A concept key of configurational analysis, in relation with resilience, is that of synergy. The latter is an interscale relationship, defined as being the degree of dependence of local configurational properties compared with the same properties evaluated globally within the urban space. If, for example, the two spatial levels are highly correlated, then local changes in the networks will have a limited impact on the configurational properties of the city as a whole and of each element of the network.

On these bases, various researches helped to better target what could be specific to urban resilience in a configurational approach. Nevertheless, these researches are carried out in a context of resilience to debilitating disruptions, but do not address the dimension of sociotechnical change, which is unavoidable in an urban geopropective approach. The debilitating disruption is flood in Esposito and Di Pinto (2015), an earthquake in Cutini (2013), an erupting volcano in Cutini and Di Pinto (2015), and the collapse of bridges and groups of targeted network cuts in Abshirini and Koch (2017). In relation to the persistence of the network's connectivity alone, groups of configurational properties are evaluated before and after the disruption. Thus Cutini (2013) and Cutini and Di Pinto (2015) suggest to follow three configurational properties: Hillier's synergy, the average connectivity, and a relative betweenness index, called frequency index (the ratio between the maximal choice index in the configuration and the theoretical maximal number of minimal paths in a same-size configuration). Configurational resilience would increase correlatively to the increase of synergy and average connectivity and to the decrease of the frequency index (because, in this case, the configuration is less dependent on a single element with very high betweenness). Koch and Miranda Carranza (2013) suggest two other configurational properties for measuring resilience, these properties being finally used by Abshirini and Koch (2017) on a city scale: similarity and sameness. If, after a disruption, the configuration of a city's street network retains the same spatial extent of the foreground network (similarity) and the same constitution of this network in terms of its components (sameness), then the configuration is considered as resilient to the disruption.

3.5.4 Morphological resilience to urban change

The challenge for urban geopropective is not to be limited to the resilience to catastrophic events, but to integrate a broader vision of the urban form's resilience to any sociotechnical change, whether slow or sudden. To do so, the urban morphological system as a whole must be taken into account: the street network (like in the configurational

approach), but also the built fabric, the plot pattern, the topography, and, obviously, land functions and use.

A complete theory of the resilient and antifragile urban form faced with sociotechnical change remains to be built, but its foundations have been laid by new theories which include the approach of the urban form's structural complexity [like, for example, in Hillier (1996, 2012) and Salingeros (2005)] and can even draw on more traditional knowledge of urban morphology (Conzen, 1960; Caniggia and Maffei, 1979). Such a theory should also enable to identify, in contrast, the most fragile urban forms. Namely those incapable to absorb new functioning to adapt to new societal requirements by gradual changes. There is a high risk that fragile forms, even when optimal in the context that produced them, become dysfunctional, and thus obsolete, are unable to self-regenerate and necessitate strong external interventions, often in the form of complete demolition-reconstruction. The most famous example is that of the modernist social housing neighborhood of Pruitt-Igoe in St. Louis, MI, completely demolished in the mid-1970s only 20 years after being built. Unfortunately, Pruitt-Igoe was only the first of many modern neighborhoods to be condemned to early demolition. Recognizing the fragility of present or planned forms is of major interest for urbanism and urban planning.

Here, the main challenges for researchers are at the same time the convergence of relatively different theoretical approaches to urban complexity and, above all, the connection with the empirical analysis of observable urban forms and of the fragility or resilience potentials that can be deduced from analyzing their properties and their transformations. Moving from general to specific must also characterize the connection between the theory of resilient urban form and the urban geopropective approach, which must be carried out on a given city in a given historical context, in which urban forms are also perceived and assessed by stakeholders through extremely powerful cultural filters (Duarte, 2010).

The reflection on the resilient urban form also meets that on the reversible city, an extremely vast subject explored by a seminal symposium in Cerisy (Scherrer and Vanier 2013). Urban planning has traditionally been poles apart from the idea of reversibility. It is precisely a change of social paradigm, the recognition of the uncertainties of the future, which raises the question of an organization of the physical city which could go back on decisions taken in a previous time. In fact, as underlined by Panerai (2013), complete reversibility never exists for the physical city, but neither does the absence of any reversibility. We think that the concept of resilient forms does tally with what Panerai identifies as being the urban form's dynamic tension between permanence and change, a tension which must be evaluated over time. In referring to the principles of urban morphology, Panerai points out how the city's morphologic infrastructure, its street and plot pattern, enables to envisage the city as being based on a powerful structure that sees short periods of history succeed one another. In its broad lines, the pattern is invariable, the

built fabric alone is temporary, variable, evolving with the new requirements of populations and activities. That is, at least, the lesson learnt from urban forms which have been seen surviving while adapting in a highly flexible manner over the centuries.

These considerations resonate with Mehaffy and Salingaros's more comprehensive reflections (2013). By developing an analogy with the ecosystems' structure and functioning, these authors lay down founding hypotheses for a theory of the resilient urban form. Any resilient urban form should be characterized by interconnected route networks and by a redundancy of route types, resonating with the strong interconnection in the ecosystems' trophic chains. However, not every pattern would be a resilience catalyst: tree-like networks and very large blocks would be particularly fragilizing for the urban form, contrary to organic closely knit networks (like in medieval cities) or orthogonal (like in the grid patterns of bastides or Barcelona and Turin urban expansions). The resilient form should also propose great diversity and redundancy of activities, in regard to building types, objectives, functions, and populations. Taking the opposing view of functionalist urbanism, Mehaffy and Salingaros see in that great diversity, considered at the city's various scales, a potential of resilience to future changes, unknowable at the time when the urban plan was drawn up. Here fragility would be linked to the specialization of the functional zoning which produces business districts devoted solely to office towers or private housing areas with residential monofunctionality. Accepting redundancy and diversity also means giving up optimization (of the form in relation to the function, of the means in relation to the results, etc.). The form is not optimized for a particular functioning, it is redundant and its "program" is open, which gives it a certain amount of adaptability in relation to the diversity of possible functioning.

Resilient urban forms are also those having a wide range of scales in their structure, from the macroform of an entire metropolitan area, to the assembling of plots, streets, and buildings, down to the details of urban design. The finest scales are even the most important, because they provide possibilities of autonomous and quick responses to urban change. We can thus understand the great fragility of major urban projects designed in their entirety, or of slab-above-the-street urbanism: any change through small additions and progressive transformations is a problem and it often becomes necessary to reinitialize the whole of the urban form by destruction-reconstruction, an admission of failure of a nonresilient urbanism. Even in resilient forms, urban change often entails a pivotal scale of response, but trans-scale relations articulate the response at all scales. This suggests a relatively autonomous level of response by individual stakeholders at the finest scale (that of each plot and building), while changing the morphological infrastructure or building large projects will necessitate greater coordination.

Finally, resilient urban forms evolve while retaining the essential of their prior structural and informational content: only the innovation which is strictly necessary to a structure

which stood the test of time is introduced (they are structure-preserving). This also brings us back to Panerai's observation (2013): to be successful, any change must rest on permanence.

In the end, as stressed by Blecic and Cecchini (2016) the urbanism of a resilient and antifragile city is an urbanism for complexity: the structural complexity is seen as a resource for the future of the urban space.

Feliciotti et al. (2016), paying considerable attention to the forms of the built environment, of plots and streets traditionally studied by urban morphology, propose an operational expression of these general principles of urban morphologic resilience. By using proxies, they show how the dimensions of connexity, diversity, modularity, efficiency, and redundancy can serve as a basis for assessing the resilience potential of real urban forms. It should be remarked that the principle of efficiency is assessed very differently from an optimization of forms in relation to a program: the form is efficient insofar as it is the result of self-organization, typically characterized by power law distributions (Salingaros 2005) and strong interscale relations. In a further publication (Feliciotti et al., 2017), the same authors show how this protocol of analysis can apply at a neighborhood scale, taking as examples the various urban forms taken in the course of the 20th century by the Gorbals neighborhood in Glasgow. Thus Victorian Gorbals' closely knit urban fabric of tenements and terraced houses was able to adapt during more than a century of sociotechnical transformations, showing great resilience capacity. The new modernist Gorbals, erected in the fifties, included very large blocks, a low level of modularity and connectivity, and high functional specialization. These fragilizing factors led to an early obsolescence and costly demolition by the eighties. The Gorbals neighborhood resulting from the transformations of the years 2000 has rectified the main faults of modernist forms. Its future is not yet written but its potential of resilience can already be evaluated as being intermediate between those of the two previous urban forms.

In conclusion, new knowledge on the complex city's form can feed the geopropective reflection on the city of the future. A few basic indications can be proposed.

First, due to the absence of strong theories to predetermine the urban future, it is not possible to propose a new form of ideal city that would be optimal for a given program. The program of the city of the future must remain open, and a plurality of forms is possible.

A rigid urban plan does not seem to befit that background uncertainty on urban futures. For a number of authors, any idea of plan should even be abandoned and urbanism should be limited to laying down a set of rules that would guide stakeholders' self-organization. Now, whether it is a flexible, reversible, and strategic plan or a set of rules, the geopropective approach necessitates a shared vision (in order to justify the rules/plans and coordinate individual actions).

This shared vision, to be fully geopropective, must give an important role to the reflection on the forms of the city of the future, and not only to its functions. Forms bind the city on the long term, especially those of the infrastructure of streets and plots. Complexity theory shows that some forms seem to be more resilient than others, that is, capable of a high level of adaptivity and transformability (antifragility).

In any case, any geopropective approach should start from the forms of the existing city, understand their potential of resistance or fragility, and understand to what extent they could face various scenarios of urban innovation. The forms identified as more resilient will have a more important role to play in a city which is bracing itself for uncertain futures. Plans and rules will have to facilitate the emergence of such forms and proscribe the production of “fragilizing” forms.

3.6 Conclusion

Understanding how territories will transform, adapt to pressures to come, and move toward sustainability is a major scientific challenge. The issue is complex, commensurate with the complexity of territorial systems of which the dynamics is unforeseeable and unpredictable. The territory is the marker of the dynamics of change, and the most accurate at our disposal. It undergoes, absorbs, and generates various evolutions and disturbances, and assimilates them in a differentiated manner in space. The resulting spatial change is the visible expression of this process. Geopropective offers various avenues to read the mechanisms of change and help to anticipate future behaviors. Analyzing the territory's spatiotemporal trajectory informs, to various degrees, on its propensity to change and on its modes of responsiveness. Its resilience capacity is a multifaceted and place-based process. Multiple components interact, some relating to the socioeconomic structure and governance, others to the organization of space and spatial configuration. Detecting the adaptive capacities of the spaces that make up the territory requires to have some depth of field.

A variety of spatial analysis tools can be used for doing so; to evaluate the resilience and fragility potential of the existing urban forms; to collect information on the behavior of stakeholders in a crisis context and detect the ferments of self-organization; to match quantitative and qualitative data so as to produce synthetical indicators; to map the resulting information; and to organize that spatialized and multivaried knowledge in a database. That spatialized knowledge base, specific to the territory being studied, is the foundation of prospective spatial modeling. Crossed with conjectures resulting from anticipative monitoring, it provides guidelines for choosing scenarios for the future.

This chapter has illustrated the contribution of geopropective to the analysis of the relationship between resilience and spatial change. The following chapter presents the range of methods and tools available to researchers.

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