URBAN FORM AND FITNESS: TOWARDS A SPACE-MORPHOLOGICAL APPROACH TO GENERAL URBAN RESILIENCE

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ABSTRACT
Assessment is one of the greatest challenges of urban resilience research. The difficulty of this task arises from the increasing complexity of urban environments and from the unpredictability of external changes, two trends that have raised environmental awareness and, consequently, led to a growing debate on the relationship between city and nature. We join this debate by looking at urban resilience through the lens of urban form. We refer to urban form as a product of the continuous tension between recovery and adaptation on several spatial and temporal scales of transformation. Although recent resilience approaches, such as *spatial resilience*, *general resilience*, and *urban resilience*, have dealt with urban form indirectly, and, conversely, some studies in urban morphology have tried to grasp the complexity of urban-natural environments, an explicit morphological perspective on urban resilience is still lacking in research. The paper is divided in three main parts: formal treatments of resilience (spatial, urban, and general), resilience of urban form (fitness, performance, and sustainability), and a network perspective on the two concepts. It concludes with a discussion on the possibility of a space-morphological approach to general urban resilience.

Keywords: general urban resilience, urban form, environmental fitness, space-morphology.

1 INTRODUCTION

As a consequence of the population growth and the massive urbanisation of the last decades, the ecological, economic and social shocks[1] encountered by today's urban environments have been increasing both in frequency and magnitude. The full extent of the causes and the consequences of these shocks, however, are difficult to determine. As cities are growing in complexity, the planning of their forms, infrastructures and services must adapt to the needs of present and future urban dwellers and to the shifts in environmental baseline conditions. Such complexity requires a better understanding of urbanization, on the one hand, and a shift in the way cities are perceived in relation to their wider environments, on the other. In *Megacities: Exploring a Sustainable Future*, Buijs et al. [1] recognize this need by highlighting two dominant themes in the debate on current paradigms of urbanization. First, they acknowledge that networks have become the driving forces of urban development, and that the scale and complexity of these networks are growing at an accelerated pace. Second, they observe that the recent increase of environmental awareness draws considerable attention to the relationship between city and nature, be it conflicting or potentially synergic.

Can we assume then that networks are the cause, and environmental awareness is the consequence of our vulnerability to disruptive change? And, if so, what is the connection of these two driving forces to urban form and resilience? The answers are not simple. Physical networks have extensively interacted with the natural environment, but, so far, the two threads of the debate – network thinking and environmental thinking – have scarcely done so. Network thinking in urbanism, a considerable branch of what Juval Portugali calls Complexity Theories of Cities [2] and a core concept of Michael Batty's 'new science of cities' [3], is an approach that deals extensively with formal or structural

[1] In the context of this paper, shocks are referred to as moments of sudden – usually unpredictable – change. Climate-change related events, such as floods and draughts, economic crises, and terrorist attacks are examples of such unpredictable shocks. They are often referred to as 'disruptive change'.

characteristics of complex (urban) adaptive systems, but with little attention for the environmental implications of networks. Conversely, environmental sciences have not sufficiently employed networks. It may be argued that their poor integration is due to their opposing orientation, in which city and nature are still regarded as separate entities, and that this lack of integration is the main reason for the vulnerability of urban environments in the face of unforeseen shocks.

The challenge, however, is not in stopping disruptive change – a task that has repeatedly proven to be impossible –, but in understanding it and, ultimately, in improving the capacity of urban environments to absorb it in one combined urban-natural system in dynamic equilibrium. Many authors have recognized that the concept of resilience, defined as the capacity of a system to bounce back, adapt, or transform in the face of disturbances, is suitable for this task [4]. Given its extensive applicability, resilience has generated several interpretations in a wide range of disciplines [4], of which *spatial*, *general* and *urban* resilience are of particular interest to urban environments. As a scholar of social-ecological systems (SESs) research, Cumming approaches resilience with a multi-scalar framework and proposes the concept of *spatial resilience*. This concept connects principles from landscape ecology, sustainability science, and complexity science, and it provides a strong framework for the analysis of Complex Adaptive Systems (CASs) [5]. *Urban resilience* adds lessons from Complexity Theories of Cities to this integration [2], a view according to which urban systems are often regarded as complex networks [3]. Moreover, as ecologists Brian Walker and David Salt suggest, every ecosystem has specific features, but also some inherent general characteristics, such as diversity, openness, modularity, or tightness of feedback. These characteristics are part of *general resilience* and represent systems' capacity to face change that is unpredictable both in nature and occurrence [4].

In the frame of this paper and the context of the two trends – networks and environmental thinking –, spatial, urban and general resilience have something in common: they are all concerned with urban form and network architecture[6]. But the nature of their relationship still needs to be clarified. How do they shape urban form? Or, conversely, how does urban form refer back to the performance of man-made or natural processes that have shaped it? The first question is typical of typology-morphology studies, while the second is characteristic of space-morphology studies in urban design [7]. The former refers to the process of formation, while the latter aims to identify processes that have led to a particular form. Although both questions are fundamental to urban morphology, the second brings a particularly interesting angle to the discussion. Given the complexity of the processes that shape urban environments, an analysis of spatial patterns is more likely to be attainable than a comprehensive system-wide description of processes.

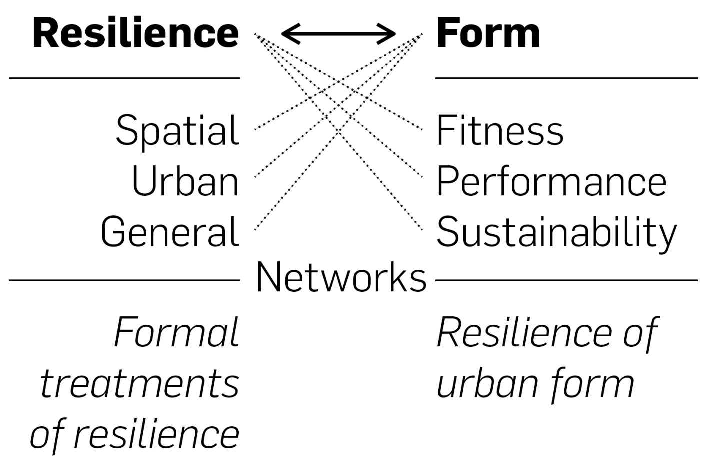

Figure 1. A theoretical framework for a space-morphological approach to general urban resilience.

Therefore, this paper proposes a combination of space-morphology with the nature-ecological approach to resilience that is already employed in urban design [7] and claims that this combination may improve our understanding of, and reaction to, disruptive change. Urban form and urban resilience are the concepts chosen to correlate the two perspectives. As shown in Figure 1, the two concepts structure the theoretical framework in two parts: formal treatments of resilience and resilience of urban form. The former identifies three spatial approaches from the resilience literature and the latter explores different interpretations of resilience in urban morphology. The structure of the paper follows the same division. First, spatial, urban and general resilience are briefly introduced and synthesized in the combined concept of general urban resilience. The second part provides a summary of the recent history of urban environmental performance research, from the 1960s until the present. The paper then discusses possible interdependencies between urban resilience and form, the current state of research on the topic, and concludes with recommendations for future investigations.

2 GENERAL URBAN RESILIENCE

Resilience has been increasingly used to describe social, ecological, and social-ecological systems (SESs). A resilient city is "a sustainable network of physical systems (the constructed and natural environmental components of the city) and human communities"[8]. Based on this definition and in light of the trends described in the introduction, we investigate how the physical form and the social fabric of urban regions will cope with future instability, while maintaining a reciprocal relationship and a dynamic equilibrium between city and hinterland.

To describe ecological systems, Holling [9] associates resilience with adaptability and transformability. Adaptability is the capacity of the actors in the system to influence resilience. It is "characterized by the ability of a system to move thresholds, change the resistance to external inputs, move the current state of the system and to manage the cross-scale interaction". Transformability is of even more interest. It is defined as "the capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable" [10]. Transformability means defining and creating new stability landscapes by introducing new components and ways of making a living, thereby changing the state variables, and often the scale that define the system. It also refers to concepts such as 'city of short distances' [11] and the 'city of small cycles' [12], within a larger interconnected context.

Vulnerability, already mentioned in Section 1, is a concept that is strongly related to resilience. Vulnerability generally has a human- or society-centred perspective, for instance, in relation to climate change. In this context the Intergovernmental Panel on Climate Change (IPCC) states that "vulnerability to climate change is a function both of the sensitivity of a system to changes in climate, and the ability to adapt the system to such changes" [13]. The perspectives of resilience and vulnerability imply far-reaching consequences for how communities are organized, infrastructures are designed and integrated, and especially on how change is handled. It is important to realise that the stability or resilience of networks is directly related to the their complexity. It is not the components of the various structures that matter, but how they are organized together as intelligent structures. In this context, Hollnagel [14] introduced Resilience Engineering with the premise that, due to a concept called 'tight coupling', the interdependence between the components of a system, be it social or technological, might become dangerously high. Thus, amongst other factors, the level of interdependency plays an important role in determining the resilience of the system.

However, resilience can be difficult to apply to systems in which some components are consciously designed [15]. The concept of general urban resilience proposed here is a synthesis of the current knowledge on spatial, urban and general resilience, discussed below.

Spatial resilience

Generally speaking, spatial consideration of a given topic or object requires an understanding of characteristics, such as size, scale, shape, and grain. Yet there is still room for interpretation, depending on the field of inquiry. Graeme Cumming [5], [16], for instance, introduces spatial resilience from the point of view of social-ecological systems (SESs). According to his definition, "[s]patial resilience refers to the ways in which spatial variation in relevant variables, both inside and outside the system of interest, influences (and is influenced by) system resilience across multiple spatial and temporal scales" [5, p. 21]. His understanding of resilience is very much rooted in complexity theory, and it contains principles of multi-scalarity, spatial relevant properties (e.g. shape, size, boundaries), and spatial dynamics driven by connectivity and feedbacks.

In architecture and urban design, spatial conditions with respect to the built environment are often linked to Vitruvius' "Utilitas, Firmitas, Venustas". Most people are inclined to call suitability for building open to objectification, usability less so and beauty actually not. The mathematician Alexander [17] was one of the first to recognize the importance of underlying structures as the basis for spatial planning, city form and the accompanying physical and social networks. His work, together with that of Habraken's [18] and Portugali's [19], forms an important point of departure for the research presented in this paper.

Design specification and translation of general concepts of resilience always comprises a scalar demarcation. In this way, stratification in the design decisions and environmental allocation comes into being, through which decisions at a higher level of scale hold as a framework for designs at a lower level of scale. However, design problems that come up at lower levels of scale should also be taken into account at higher levels of scale,. In reality, the scale levels have "sliding" boundaries and each level of scale has its specific, often limited, absorption capacity[2] or scope[3].

Urban resilience

Urban resilience is a topic that has only recently come more to the forefront of addressing disruptive change in urban environments. Most of the findings in resilience research are still in the field of ecology, waiting to be tested and translated to urban systems. Studies, such as those compiled by Picket et al. [21] or Eraydin and Tasan-Kok [22], are some of the few trying to explicitly refer to resilience in urban planning and design, but their inquiries are still open-ended. Agreement on the meaning and application of resilience in urban planning is still expected.

According to Portugali, the city can be understood as the product of self-organization. This is somewhat contradicted by the heuristic that cities are the symbols of planned action with ridged boundaries, districts and urban fabric. While spontaneous self-organization seems diametrically opposed to planning that is aiming for controlled order, cities may be understood as *dual* self-organizing systems in which every city dweller is a potential planner at a particular scale [23]. As we saw earlier, spatial resilience is strongly connected to complexity. Thus, if we consider the dual-complex character of cities (spatial systems by definition) and the accelerated pace of current urbanization, the importance of studying their resilience becomes paramount.

General resilience

Brian Walker and David Salt distinguish two types of resilience: specified and general [4]. So far, specified resilience has received most of the attention. A considerable part of resilience literature has dealt with case studies, stories about how resilient, say, a coral reef, a forest, or a human individual is. In this sense, components of resilience are characteristic of a particular system, and thus cannot necessarily be applied in systems with a different nature or in a different location. All these cases answer the well-known question: 'resilience of what to what' [15], or even 'resilience of what and to where and at what temporal and spatial scales' [24].

For general resilience, on the other hand, these questions are irrelevant. In normal circumstances, one does not doubt the immunity of a living organism to a particular diseases or a specific external disturbance. An immune system is meant to prepare and protect an organism to as many external

[2] The absorption capacity has a technical and a social component. For example, from a technical perspective, it can result from the maximum amount of daylight that is available and can be converted for the purpose of natural purification processes or in order to generate solar energy (in terms of W/m^2). Or, it may also result from social limitations (which are not always visible). It is important to combine the two.

[3] Scope plays a role in specific types of transport. It can be compared to how the size of settlements used to cohere with the way of transport, e.g., 5 km as a diameter for the "walking town", 20 km for the "horse town", e.g. [20], or with the number of inhabitants (e.g., 50,000 for the Romans, related to governability).

changes as possible, known or unknown. Thus, we believe that like an immune system, a resilient system has general characteristics that can be enhanced. And if we take the metaphor further, we claim that resilience is a form of immunity. General resilience is, in Carpenter et al.'s words, "the capacity to absorb shocks of all kinds, including novel and unforeseen ones" [25, p. 3250] or, as Walker and Salt suggest, a sum of inherent general characteristics that are found in every system, such as diversity, openness, modularity, and tightness of feedback [4, pp. 90–100].

Yet these attributes cannot be easily assessed. According to Jon Norberg and Graeme S. Cumming, "the world is essentially uneven" and one of its main characteristics, diversity, "is most valuable during times of change, when the integrity of a complex adaptive system is threatened" [26, p. 12]. Following this line of reasoning, general resilience has to be thought of and assessed by looking at cities as complex adaptive systems.

3 RESILIENCE AND URBAN FORM

As cities grow in complexity their spatial morphology, infrastructures and services must adapt to the needs of present and future urban dwellers and shifts in environmental baseline conditions. Interestingly enough, while urban regions produce two-thirds of global emissions, urban dwellers on average use 40 per cent less energy than suburbanites [27], [28]. From this perspective, the agglomeration effect that allows urban regions to have high population densities and economic activity could serve as a potential asset in the development of adaptive strategies towards mitigating the effects of disruptive anthropogenic change (e.g. climate change) relative to energy generation and much more. The question is, however, to what extent urban form should be adapted to better cope with disruptive change.

During the last five decades, several studies have sought to understand the impact of urban form on the environment. Environmental fitness, sustainable urban form and the environmental performance of urban patterns are three approaches that have not explicitly (or centrally) used the term 'resilience', yet their scope has considerably overlapped with resilience thinking. Therefore, this section introduces the environmental fitness discourse of the late 1960s [29], with a special emphasis on Ian McHarg's work [30]. Then, it outlines the current descriptions of sustainable urban form given by Burton et al. [31] and Jabareen [32], and it introduces Alberti's [33], [34] investigation of urban patterns in relation to environmental performance.

The form of a fit urban environment

In 1968, the Smithsonian Institution published the papers delivered at its Annual Symposium under a title that was very representative to the concerns of that time: *The Fitness of Man's Environment* [29]. The fifteen contributors – biologists, anthropologists, architects, and planners – acknowledged that the environmental changes caused by urbanization had led to undesirable consequences and that a future vision on the performance of urban environments was needed. Environmental fitness – just as resilience is today – was the common denominator in their writings. In parallel, and very shortly after the Symposium, Ian L. McHarg – one of the participants – published *Design with Nature* [30], a book that, since then, has received considerable attention in the field of urban design and landscape architecture. Strongly influenced by one of his precursors Lawrence J. Henderson, author of *The Fitness of the Environment* [35], McHarg disqualifies "the old canard 'form follows function'. Form follows nothing", he says, "– it is integral with all processes. Then form is indivisibly meaningful form, but it can reveal ill fit, unfit, fit and most fitting. […] Fitness is then by definition creative and will be revealed in the form of fitness that is life-enhancing" [30, p. 173].

This worldview had increasingly dominated the discourse in urbanism at that time, most certainly because scientists were becoming aware of the environmental consequences of the unleashed urban growth of the previous decades. The separation of city and nature had reached a point in time when it could not be sustained anymore. That dichotomy was not just the consequence of urban development, but more than that: the cause of environmental degradation. As a result, it became an acknowledged threat to human well-being. The concept of fitness, together with subsequent applications, came as a possible solution to this crisis.

As many planners and designers of that time were fascinated by the image of blues, greens and greys of Earth seen from space, McHarg applied the concept of fitness with a careful regard for land cover and land use. In his view, natural-process values are inversely proportional to urban use suitability. For instance, land covers that are richest in biodiversity – surface water or marshes – are the less hospitable for urbanization, while flatland, the less likely to host abundant biodiversity, is the most suitable for urban development [30, p. 57]. Yet, as we have observed throughout history, these two extremes tend to pair up; urban environments have grown as close as possible to rich natural areas, such as floodplains and deltas. Recently, their relationship has become conflicting: urbanization has ended up damaging its environments, rather than shaping it in a synergistic way. In addressing the spatial dimension of this conflict, McHarg claims that open-space distribution in urban environments must respond to natural processes [30, p. 65]. In other words, urban form – as a result of the spatial distribution of open and occupied land – was (and is) considered highly relevant to the study of the relationship between city and nature. According to him, "it is […] essential to understand the city as a form derived in the first instance from geological and biological evolution, existing as a sum of natural processes and adapted by man. […] This enquiry is described as an investigation into the given form – the natural identity – and the made form – the created city" [30, p. 175].

His concern for the separation between *given form* and *made form* is obvious. Yet he, together with his contemporaries, still seems to look at city and nature separately. Even though they offer valuable solutions, in essence they praise nature and blame the city. As the relationship between given and made form has suffered considerable changes in the years that followed, an increasing number of researchers have shared McHarg's concern. Not the character, but the spatial extent of this relationship has changed. Today's urban reality is different from that of the 1960s in the sense that man-made networks – as pointed out in the introduction – have grown into the main driving forces of urbanization, leading to a complex, dense and globally interconnected web of urbanization. Urban environments (rather than 'free-standing' cities) are intertwined with natural processes, thus increasing our environmental impact at an accelerated pace. The problems anticipated by McHarg's generation have grown into a harsh reality today, but the clarity of his observations is still valuable for current research.

Sustainable urban form

Recent studies have continued to show interest in the environmental performance of cities under the umbrella of sustainability [31], [32], [36]. These studies have focused on the relation between land-use and transport systems and, accordingly, aimed for assessing these two features based on "archetypal urban geometries" [37]. It is commonly agreed that urban concentration, in contrast to dispersion, is a feature that makes urban form more sustainable, as it reduces travel distances and, correspondingly, environmental impact. Jabareen, for instance, identifies seven design concepts – compactness, sustainable transport, density, mixed land uses, diversity, passive solar design, and greening – and four models of sustainable urban forms – neotraditional development, urban containment, the compact city, and the eco-city [32]. Based on these two dimensions he proposes a matrix to assess the sustainability of the four types of urban form. Although the compact city has received extensive support [38], it has been acknowledged that a wider understanding of urban diversity is needed [31].

This research context faces two main challenges. First, as Marina Alberti states, the question of environmentally appropriate urban form still lacks a theoretical framework [33], [34]. Following Moudon's classification of research clusters in urban design [7], we propose a theoretical framework that integrates both a nature-ecological and space-morphological approach to urban environments. Second, researchers addressing the relationship between urbanization patterns and environmental performance very often look for environmentally appropriate urban forms [31]. In the context of resilience, however, we believe that not forms but principles of formation are key to this relationship. A compact city can be equally resilient as a dispersed urban settlement, as long as it maintains a synergic relationship with its environment.

Urban patterns and environmental performance

In an earlier paper, Alberti [33] summarizes the state of research conducted on interactions between environmental performance and urban patterns in a matrix of four environmental variables – sources, sinks, support systems, and human well-being – and four structural variables – centralization, density, grain, and connectivity. Following this 'synoptic review of existing studies', she highlights four major implications for urban theory:

- Environmental processes are drivers of change;
- Consideration of scale;
- Including uncertainty into our enquiries;
- Consideration of thresholds.

Although she only briefly mentions resilience in relation to environmental response to change, the implications outlined above clearly resonate with the features of resilience. Yet sustainable urban form research has remained parallel, almost as an alternative to the emerging field of resilience.

4 URBAN NETWORKS

One of the main challenges of any research dealing with the resilience (fitness, sustainability, or performance) of a system is the factor of uncertainty and complexity. Such a context requires tools that are fit to grasp and analyse the patterns and processes at hand. Network thinking in urban design, an approach that has emerged under the umbrella of Complexity Theories of Cities [2], has gained popularity among morphologists interested in complex urban adaptive systems [3]. As we show in this section, this perspective is useful not just for describing the form of complex systems, but it may, ultimately, serve to draw inferences about processes and system performance, i.e. resilience, too.

Generally, the study of networks is part of a broader field of science called complexity theory. Complexity theory aims to understand the rules of interaction between parts, such as atoms, amoeba, and biota in natural ecosystems, cars moving in traffic, or trades within the stock market, through the use of computer modelling. While a computer model can never truly represent the fidelity of the real world, there are some very useful ideas within complexity theory that can be used to better understand and potentially strengthen the basic principles of interaction within urban systems in the face of looming disruptive changes [39].

One essential concept to complexity theory is the complex adaptive system (CAS) and its characteristics of emergence and self-organization. Emergence refers to patterns and meaningful order that emerge spontaneously out of the interaction of parts within a complex system. These patterns are identified by accumulative change over time and can occur at different scales, for various reasons, and are usually difficult to predict (e.g. the shape of a flock of birds moving in the sky versus the collective will of the global economy). Self-organization refers to how complex order arises from the interaction of agents or components in an initially disordered system. A key element of CASs is that they have multiple potential equilibriums. From this perspective, the city serves as the perfect example of a CAS, where humans fulfil the role of agents, expressing behaviour based on internal rules (desires, actions, beliefs) and external rules imposed by both society (laws, culture) and the physical environment (streets, parks, rivers, etc.). But these emergent features (i.e. bottom-up initiatives and community building) of CASs are equally relevant to the description of urban form or formation, be it on neighbourhood, district or even city level of scale. As cities are the hubs of wealth, innovation, creativity and heterogeneous populations, they are also simultaneously hotspots for disease, crime and environmental pollution [40]. Additionally, similar to the historical findings of Diamond [41], network theory has shown that the world's most important networks (economics, politics and ecosystems) are perpetually on the brink of instability and collapse [42]. As a result, there is almost a universal law within nature in which history is frequently marked by sudden and overwhelming events that completely shift system dynamics (i.e. dynamic equilibrium) [8].

Strogatz and Watts [43] studied the distinction between social networks and other networks and found that whether a network is created by man (power lines, social network, the world wide web) or by nature (neural net in the brain, nervous system of a worm) there is a distinct underlying "small-world structure" [42]. Small-world networks [44] are characterized by having a few degrees of separation between dispersed interacting parts due to weak, bridging links and being highly clustered around particular important hubs. At some base level, regardless of the conditions in which networks developed there is an identical architecture [12], [39].

Further, it can be argued that the ultimate goal, when elaborating on resilient responses to city growth and continuing complexity of cities, is to introduce the principles of fitness and 'economies of scale'. The idea is to create a complex, adaptive aristocratic structure of separate networks, or preferably of the whole that they form together. It implies 'scale invariance' and 'self-organization', with change as a precondition.

According to Barabási et al. [45], city and networks than should grow (change) continuously, e.g. through new links and (decentralized) clusters. However, new links also need to be connected to the whole following the power law, with so-called "multi-connected" links following the principle of 'preferential attachment'. This principle implies the process that, in case of growing systems or networks, they expand because of new vertices being added that are connected with the vertices already present in the system. For most of the networks, this happens according to preferential attachment, dependent on the extent of connectivity of the vertices that are already there, the so-called 'effective attachment' [45], [46]: the bigger the connectivity the bigger the chance of a new link. So the existing city form and layout of networks, and their interconnections define growth, and therefore indirectly the resilience of the whole system.

Eventually, this combination of growth and "preferential attachment" is responsible for the scale-free distribution and the possibility of 'power law' scaling as observed in real (e.g., natural) networks. In order to understand the necessary process of clustering within this process, for the sake of resilience, it is of importance to know the underlying powers of the principle of 'preferential attachment', the 'rich-get-richer' principle. Regarding this principle, Bianconi and Barabási [47] argue that the aspect of fitness, similar to that to which McHarg [30] referred regarding natural systems, plays a role in competitive networks. This is referred to as the principle of the 'fitter-get-richer', where the aspect of competitiveness implies competition within networks rather than competition between networks. The aspect of fitness must be defined differently for the various networks. In this type of system, a node (e.g. an urban subcenter) can only link further at the cost of other nodes: the (theoretically) competitive character of this type of network is the result of the fact that already existing nodes in a system have to compete (linearly, as demonstrated) with a increasing number of other nodes in the continuous growing process of the system.

It is expected that the scale-free character is a principle, generic or universal for complex networks such as cities [45], [46], irrespective of their dynamics, geometry or structure [46]. The scale-free heterogeneity of transforming and competitive complex networks is a direct consequence of the principle of self-organization by local decisions made by individual 'vertices' and based on information that was led through the communication systems to the more visible, 'richer', heavier-linked vertices, irrespective of the nature and the source of this visibility [44], [47], [48].

5 DISCUSSION: TOWARDS A SPACE-MORPHOLOGICAL APPROACH TO GENERAL URBAN RESILIENCE

In summary, we explored the reciprocal relationship between urban form and resilience, first from an ecological, and then from a mostly morphological point of view (see Figure 1). We introduced the concept of general urban resilience and three chronologically consecutive interpretations of urban form in the context of environmental fitness. Then network thinking was introduced as a promising and overarching approach capable of describing the complexity of urban form and resilience. The reason for this exploration stems from our general hypothesis that the form of urban environments may be used to assess or build their resilience. Hence, this paper intended to discuss the potential of combining the knowledge of space-morphology and general urban resilience.

In our exploration, we identified four challenges in correlating urban resilience and urban form. First, the literature dealing with urban resilience does not have its own instruments; it still uses concepts from other fields, in which resilience is more consolidated. Urban environments are dual complex systems, as Portugali warns us [23], meaning that both the city and its agents – humans, communities, organizations – are complex systems in a dynamic equilibrium. The linkage to natural systems has been challenged by certain social scientists because it neglects the sociological fact that humans are malleable and conditioned by their social environment, not the natural environment [50]. Human behaviour is primarily influenced by societal norms rather than immutable natural laws. From this perspective, planning cities as a metaphor for a large biological entity is naïve because human relationships with the environment and other humans are more complicated [8]. In this sense, the frameworks used in ecology, for instance, cannot be directly applied to urban environments, as they will not fit the character and extents of urban processes. Second, the inconsistent terminology of research dealing with the relationship between environment and city seems to create confusion. Environmental fitness, sustainability, and environmental performance presented here are concepts developed with the same incentive as resilience: the causes and the consequences of environmental impact. Third, as Alberti pointed out in 1999 already [33], the literature still lacks a conceptual framework that integrates urban patterns and environmental performance. And fourth, current research in urban design is taking a nature-ecological approach to urban resilience, leading to methodologies adapted from ecological research that do not integrate existing (and consolidated) urban design research methods.

Therefore, we propose the following:

1. The concept of *general urban resilience* provides a coordinated knowledge of spatial, urban and general resilience. Additionally, research on general urban resilience requires a framework capable of assessing the complexity of urban environments. Networks offer a framework that is already applied in Complexity Theories of Cities and that is compatible with pattern-process descriptions characteristic of (landscape) ecology.
2. We extend our knowledge base on urban resilience and form to include studies that do not explicitly refer to resilience, but which have the same focus. There are similarities between studies concerned with resilience assessment and those dealing with the measurement of urban form in relation with environmental performance. These studies need to be correlated before a reliable theoretical framework and an integrated method of assessment can be developed.
3. The theoretical framework illustrated in Figure 1 contributes to a common body of knowledge for nature-ecology and space-morphology.
4. Space-morphology brings methods of analysis already familiar to urban design research, such as urban network analysis.

This paper contains the preliminary findings of an eight-month research; therefore, results on resilience and urban form cannot be claimed yet. However, the conceptual framework provides a good starting point for future research. A correlational research of spatial patterns and urban resilience indicators is essential for a reliable integration of nature-ecology and space-morphology. In addition, there is still need for research on how networks can be applied to assess urban form. Finally, both correlational research and network analysis of urban form have to be applied to case studies.

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