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Original Article/Research

The livability of spaces: Performance and/or resilience? Reflections on the effects of spatial heterogeneity in transport and energy systems and the implications on urban environmental quality

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Abstract

Cities can be seen as systems of organized complexity formed by interrelated and highly dynamic sub-systems. This paper reflects on the interactions and tensions between socio-ecological and/or socio-technical sub-systems in cities and their capacity to either improve or block urban processes. In this context, spatial heterogeneity could enhance or hinder the performance and resilience of critical urban sub-systems such as transport and energy. The consequence of this interaction might be detrimental to environmental quality (air and acoustic) and the livability of urban areas. This rationale may improve political and expert decision-making processes toward sustainable, resilient and livable cities.

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Keywords: Spatial heterogeneity; Environmental quality; Urban systems performance; Urban resilience

1. Introduction

A new and complementary way of thinking for a sustainable built environment involves the study of urban areas in terms of both socio-ecological and socio-technical systems. In such an approach, cities are complex adaptive systems capable of facing risks and unforeseen

adversities. The system is composed of a series of interacting and interdependent sub-systems, which comply with the components' arrangement and processes that organize and guarantee life in urban areas. One key characteristic of such sub-systems is performance, understood as the system's effectiveness to maintain a certain quality level. Another important characteristic is resilience, expressed as the capacity of a system to absorb, adapt, and restore its performance after a disruption.

In the past decades, the study of urban form has become more complex, shifting from the physical characteristics of a built-up area to a multifaceted approach (Larkham,

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2004). As part of this new approach, the socio-spatial processes that generate urban form need to be considered. By understanding the complexities of urban systems and their sub-systems, planners could identify, learn and retain the qualities of urban form that are essential to guarantee sustainable development. With this vision in mind, cities should guarantee certain intrinsic abilities to face change, like the possibility to relocate urban objects (Roggema, 2014). Historically, the focus of urban form has been on the normative aspect, neglecting its analytical approach that embraces the relation between urban form and urban life (Marcus, 2007). In this direction, the urban environment can become obsolete, with no capacity to absorb, for example, the speculation on a future development, or the pressure and the environmental consequences of demographic changes. From a socio-ecological perspective, the main challenge is how to improve the livability of spaces and avoid damaging the quality of life on a global and individual level. To achieve this desired level of urbanity, certain trade-offs between urban sub-systems are necessary.

Cities hold several environmental challenges: they occupy 3% of the land surface, host 50% of global population, consume 75% of natural resources, produce 50% of the global waste and emit 60–80% of greenhouse gases (UNEP-DTIE, 2013). Without environmental quality, cities become hostile places, neglecting the chance of space optimization coupled with an improved environmental performance (van den Dobbelsteen and de Wilde, 2004).

A key challenge is to look at cities as systems of organized complexity formed by interrelated and highly dynamic sub-systems, including individuals engaged in different interactions (Atun, 2014; Dantzig and Saaty, 1973). Within the framework of achievement of current and future citizens' needs, we claim the importance of the underlying socio-technical systems in the built environment.

In such complexity, spatial heterogeneity is seen as a key strategy to increase the livability of cities. Heterogeneity is seen as an opportunity to allow the development of a suitable physical environment, not only as a reaction to modernism postulates of segregation (Fainstein, 2005). On one hand, spatial heterogeneity allows the diffusion of risks as it increases redundancy. However, it compromises optimization and tends to reduce performance of interrelated sub-systems (e.g., transport, energy, water etc.). In this case, spatial heterogeneity constrains underlying systems in cities, disrupting the capacity to reach certain equilibrium. Without this dynamic equilibrium, environmental quality as a leading vision of resilience and sustainability is not guaranteed (Wilbanks and Fernández, 2014).

This paper sets up a niche of discussion about the tensions between the capacities of urban socio-ecological and/or socio-technical sub-systems to either improve or block urban development. The focus lies on juxtaposing the effects of spatial heterogeneity in two major urban sub-systems, energy and transport. The reflection addresses the tension between urban performance and

urban resilience and the consequent value of the entropy concept as an interaction capable of enhancing or hindering the quality of life. The emphasis is on the implications that this tension may have on urban environmental quality and livability. These implications are analyzed through the effects that spatial heterogeneity, transport and energy sub-systems have on the human habitat and livability, attending to main environmental stressors as air and noise pollution. The intention is not to analyze whether all kinds of spatial heterogeneity fit to the idea behind the current study, since some limitations in terms of scale and time may constrain the benefits of spatial heterogeneity to resilient behavior. Resilience of one scale is not automatically linked to another, allowing space for trade-offs in resilience between scales (Chelleri and Olazabal, 2012). This approach has been defended in previous studies (Boyd et al., 2015) and also supported in the present paper.

A further exploration is done on the relations, interdependencies and tensions between the socio-ecological perspective and the social-technical one of urban systems. The two perspectives are often subordinated to each other, thus reducing either performance or resilience. Does spatial heterogeneity have an impact on urban environmental quality due to the enhancement or hindering of the energy and transport systems? Is it plausible to reach equilibrium between the performance and resilience of these systems without giving up to urban environmental quality and the demanded spatial heterogeneity?

2. Urban form coevolution and spatial heterogeneity

Preoccupied about the physical representation and perception of the city in the book *The Image of the City*, Lynch (1960) stresses the importance of urban form in the everyday life of people. According to Lynch (1984, p.47), the urban form or the “physical environment” refers to the “permanent objects” in cities, such as buildings and streets. In his “normative theory”, Lynch emphasizes the link between permanent objects that compose urban form and human values (Lynch, 1984).

Over the last few years, human and ecological systems have been increasingly regarded and studied as interconnected ones. Such interaction derived land use decisions from urban form and vice versa. The urban landscape needs to be seen as productive fields (Waldheim, 2016) where an outdated view on space as *form* need to be challenged and seen as interlinked processes that interact in both time and space (Corner, 2006). The spatial patterns and the need of underlying infrastructures arise in a certain spatial heterogeneity in the built environment (Alberti, 2005).

Extending Norberg and Cummings' (2008) study, spatial heterogeneity depends on combinations of material, relative and relational aspects of urban form. This results in non-random spatial and temporal differentiation, forming some sort of a pattern. These asymmetrical conditions of urban form are mainly sustained by plural access to

urban resources, dynamics of spatial processes and the potential capacity of resources.

The study of urban form embraces more recent perspectives concerned with the complexity of social, political, ecological and economical processes. Systemic qualities found in resilience research were related to urban morphology studies (Batty, 2013; Marcus and Colding, 2014). The interaction resulted from the constant change on networks and patterns. Spatial heterogeneity is an interdependent shaper of underlying systems, impacting urban environmental quality and the livability of spaces, affecting performance and resilience capacity. Therefore, the production of space is submitted to this coevolution; as their environment changes, cities need to change to ensure best fitness. Even more, when they change, their environment changes too, as part of a coevolution process.

3. The value of spatial heterogeneity: the tension between urban performance and urban resilience

As part of urban form coevolution, spatial heterogeneity has to be thought and evaluated by looking at cities as complex adaptive systems. During stable conditions, most cities tend to lose diversity, while the performance of each urban system may increase and optimize itself. Conversely, a higher degree of diversity acquires more value when change is needed, when the system is threatened. Spatial heterogeneity in a socio-ecological system does not act independently. The spatial heterogeneity and the performance of the underlying systems need to be understood as dynamic, relative and relational properties of resilience.

From a socio-technical point of view, urban systems look after improving their performance by properties such as efficiency, homogeneity and mono-functionality (Fainstein, 2005). On the other hand, resilience, defined by properties such as diversity, modularity, and redundancy (Walker and Salt, 2012; Zolli and Healy, 2013), often has low priority in city governance due to its costliness, inefficiency, and long-term uncertain application.

From a socio-ecological point of view, city governance often neglects the fact that urban systems are coupled. Walker and Salt (2006) pointed out that the optimization of performance and efficiency fails when changes in bigger systems are encountered. Urban performance has to be measured in a long-term perspective, in which resilience properties gain more importance in building overall performance (Fig. 1). Within this approach, improving resilience does not decrease performance; on the contrary, it is a form of increasing long-term performance.

This approach helps to find answers to the research question presented in the present paper: To what extent and how does spatial heterogeneity enhance or hinder the performance of the energy and the transportation systems, affecting urban environmental quality and the livability of spaces? Therefore, for the urban system to be both highly performing and resilient, two goals have to be

accomplished: systems must be efficient to allow better quality and they must be also flexible and adaptable to change.

3.1. Assessment of spatial heterogeneity

One key question for understanding urban form is the scale and the boundary conditions of the studied situation. A relational understanding needs to consider both physical and associative variables, as well as the context of a specific situation (Björling, 2016). A second problem is the identification of relevant indicators for the performance of urban form in the manifold spectrum of aims to which society is heading. This complexity needs a methodological approach that can oscillate between including and excluding relevant and meaningful factors, preconditions and consequences. On the other side, understanding the urban form demands awareness of the events that affect the components and actors previously seen as irrelevant ones (Levine et al., 2012). Searching for connections and links between complex systems is a knowledge production of trial and errors; it is a learning process (Simon and Cilliers, 2005).

Composing actors and components into relevant configurations in a pro-formative process may identify Key Performance Indicators. The process oscillates between focusing on defining problems and revealing processes, identifying relevant scales and system boundaries. Those indicators may include “cumulative and synergistic impacts” (Alberti, 1999), characterizing links between the underlying systems influencing the urban environment (e.g. diversity of land uses, building intensity, mobility modes, building typologies, accessibility patterns, etc.). This assemblage thinking (DeLanda, 2006), together with a relational understanding of space (Harvey, 2006), deconstructs and reveals the qualities of the links as intercreative ones. The previous makes possible the identification of specific, significant processes and functions within urban systems that sustain the urban landscape within the concept of livability of spaces.

3.2. Performance and/or resilience? Cities and entropy

From the efficiency and flexibility paradigm, spatial studies have been using the idea of entropy to measure the maximum possible dispersion (Cabral et al., 2013), especially since Theil (1972) reinterpreted the Shannon's entropy formula, named also the Shannon equitability index. As such, entropy can tolerate a range of values in which neither the performance nor the resilience of urban system is compromised.

Using this concept, a desirable low entropy value in the transportation system is intended to accomplish the efficiency and organization of the system as an example. However, heterogeneity is needed to resist to disturbances in its function. Hereof, measuring and monitoring the entropy levels might help in the understanding of the performance and possible threats of the urban systems.

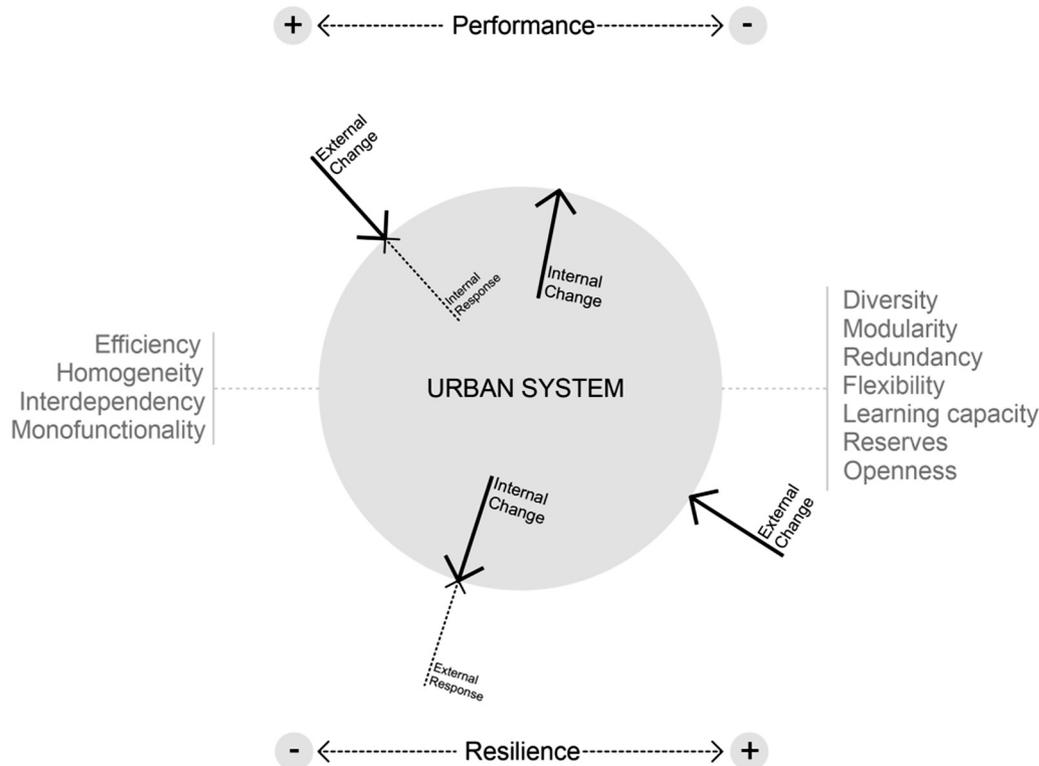


Figure 1. Framework of internal and external changes on urban systems. Tension between performance and resilience.

4. Livability of spaces - environmental quality

The spatial development of the city is extremely important to guarantee the livability of spaces. Nevertheless, a “lock-in” effect is attached to the urban form, meaning that once it is defined, retrofitting is not only complex but also expensive (Salat et al., 2014), impacting every city system. Alberti (1999) pointed out that “...the most direct indicator of environmental stress in a city is its population’s state of health and wellbeing...”.

The importance of the environmental quality concept brings up the tension between performance and resilience. The European Environment Agency (EEA) stated in the report *The European Environment - state and outlook 2015* (EEA, 2015) that urban systems are partly efficient, however, they create large exposure, diminishing the quality of the urban environment. The disconnection of urban systems in the urban planning process may increase the pressure on the urban environment and threaten people’s health and wellbeing. Landscape fragmentation and transport emissions are examples of triggers of the environmental pressures present in urban development process (EEA, 2015).

5. Urban form and underlying infrastructures - effects on human habitat: urban air and noise pollution

Within the present tension between socio-technical and socio-ecological perspectives, the aim is to ensure livability, allowing greater environmental benefits as mentioned in

the 7th Environment Action Program (Official Journal of the EU, 2013). On such a program, the purpose is “to safeguard citizens from environment related pressures and risks to health and wellbeing”.

Two of the systems that play an important role in the environmental degradation of both perspectives are related to the energy and the transportation systems. Mobility patterns and transport design have a direct impact on the urban sound environment. On the other hand, energy consumption affects the air quality and the global warming potential. Road traffic is categorized as the major contributor to environmental noise in urban areas (EEA, 2014) and the highest one in terms of greenhouse gas emissions, GHGE (Field and IPCC, 2012). The transport system is one of the main factors responsible for the failure to comply with the recommendations for air and acoustic quality in the built environment.

Noise pollution is the first cause regarding environmental nuisance in the WHO European region (EEA, 2014). It is marked as one of the main problems related to sleep disruption, diminishing the wellbeing of people. Almost 20 million of adults are annoyed by environmental noise, affecting daily activities as well as social interaction (Evans, 2012). It is also cataloged as a major environmental health problem, causing cardiovascular diseases and other physiological symptoms (WHO, 2011). The interesting connection is that most of the major effects in our sound environment have to deal directly with the production of space, the effect the source has in its surrounding spatial context. A certain urban morphology is making

possible to have certain effects and acoustic qualities. The combination of spaces (e.g. spatial heterogeneity) is enabling one result or another.

On the other hand, air pollution is considered not just a local problem, rather a global one. Pollutants are transported around the globe, resulting in an environmental problem elsewhere. It is the first cause of environmental risk factor of premature death in Europe.

5.1. Performance?

The increasing awareness on environmental impact has already started to put pressure on new approaches in urban planning processes (Wilbanks and Fernández, 2014) as well as in environmental policies. Today's urban development strategies are shifting toward the increase in spatial heterogeneity in an attempt to improve the offer of services and reduce travel distances, while providing more livable spaces (Zheng et al., 2014). The question remains if spatial heterogeneity is synergic to infrastructure performance. If unevenness and spatial heterogeneity are recognized as tools to avoid threats, the study of urban form may enhance the concept of urban spatial complexity and its implications for the environmental quality. The first conclusion is directed to ensure urban environmental quality, where certain types of trade-offs are necessary between alternative urban patterns.

Smith et al. (1997) explored the concept of urban planning in terms of quality of the urban community and the physical form. This was done through several principles that can help to understand how the physical variables are contributing to the idea of quality in a community. Diversity as a general concept was found as the third principle in importance with respect to its relation with physical form. More concrete, guidelines for urban planning might be considered in analyzing the impact of noise in both health and wellbeing with a long-term perspective (Gidlöf-Gunnarsson et al., 2012; Kropp, 2014). In this sense, urban form policies are crucial to guarantee sustainability in the urbanized landscape (UN-Habitat, 2004).

However, current approaches demand for a more systemic and integrated perspective. Several studies have pointed out the relation between urban form, with a strong influence on the traffic pattern and the consequent acoustic quality (Silva et al., 2014; Gidlöf-Gunnarsson et al., 2012; Tang and Wang, 2007). An enormous challenge is confronted due to the direct impact on the mobility and the productivity that the society demands (EEA, 2015).

Regarding air quality, the urban form and the street configurations have a cumulative effect on emissions, exposing people to direct inhalation or through contaminants that are transported through the air (EEA, 2015; Pandian et al., 2009). The spatial layout has also consequences in the air quality due to energy consumption and resources (Futcher et al., 2013; Ishii et al., 2010; Jabareen, 2006). Fonseca and Schlueter (2015) found that spatial heterogeneity influences the performance of district

energy systems. First, it constrains the penetration of renewable energy sources by limiting the vicinity of resources to customers. Second, it affects investments in infrastructure and the size of conversion, storage and distribution systems of energy.

In this manifold of interactions, there is a strong coupling with the methodological approach needed in the assessment of spatial heterogeneity. An assemblage process is demanded, including and excluding relevant factors and especially the consequences in an interactive learning process. Performance measurements with Key Performance Indicators can help in the assessment of consequences derived from the environmental pollutants caused by the transport and energy systems (e.g. in the energy system: energy consumption per household, GHGE per area associated to the production of energy. In the transport system: people exposed to high noise levels due to road traffic, noise annoyance, presence of public areas cataloged as quiet ones, GHGE due to mobility, etc.)

5.2. Resilience?

The present paper supports the idea formulated by Awiti (2011), according to which resilience seems to be the missing fragment in the sustainable development discourse. By definition, sustainable development is limited by the expectations of achieving more efficiency (reducing the use of inputs), a view that has no capacity to resolve the constraints imposed by the fact of living in a limited environment. Resilience, on the other hand, aims at enhancing overall system performance, adding another dimension to sustainable development.

Resilience evaluation can be performed by three attributes: disturbance magnitude that can be absorbed by the system to retain its identity; the degree of the system to re-organize; and the ability to increase adaptability (Awiti, 2011). Adaptive capacity becomes more important when socio-ecological and socio-technical systems are linked (Adger et al., 2005). Hence, cities are in constant need to change, and, ignoring this fact is only making them more vulnerable to threats. The goal is to overcome the unwanted situations, providing anticipation mechanism to avoid crossing the threshold. At the same time, the intention is to guarantee the urban environmental quality demanded in the quality of life concept.

Thresholds are crucial when assessing the resilience of a system. Socio-ecological systems can exist at different situations of stability: one before the threshold is reached and another one when the threshold is crossed, changing its behavior and the interactions with the other systems. Still, there is a certain ambiguity and complexity on environmental targets or thresholds in urban environments. That ambiguity is mainly due to the fact that urban environmental quality and good performance of the underlying systems should not be compromised. In such compendium, most urban systems, including energy and transport, are highly reliant on underlying systems for their well functioning.

Moreover, the lack of capacity to reach consensus at European and/or national level has forced the emergence of local regulations to deter the fulfillment of the objectives set by the WHO, the EEA or national regulations. A greater effort is required to get, for example, the social and economic consequences of inaction regarding air and noise pollution (EEA, 2014; OECD, 2012). Recently, this concept of inaction has become more and more important in terms of the irreversible impact it has on the environment. Interestingly, the previous idea interacts with the thresholds of resilience thinking, where for example, policy inaction can trespass the environmental damage, interacting with other systems such as land use decisions, etc.

Roggema (2014) identified four possible mechanisms dealing with the concept of thresholds: move thresholds; make them difficult to reach; move the system away from the threshold; and manage cross-scale interactions to avoid loss of resilience. Still, these mechanisms need to be adapted to the full spectrum of the urban processes. Cities must bring opportunities to reconfigure their urban fabric, relocate functions, uses and urban objects and adjust themselves to changes, while providing livable spaces, including the idea of a clean environment.

Based on this premise, Fonseca et al. (unpublished results) experimented the concept of spatial heterogeneity and performance of transport and energy systems for an urban community in Switzerland. The authors found that increasing the spatial heterogeneity does not go against a good performance or resilience of infrastructures and its consequential impact on environmental conditions regarding air and noise pollution. Moreover, it seems that the spatial heterogeneity is a key to the coexistence of users' activities and spatial functions, fostering the livability of the spaces.

6. Negotiating spatial heterogeneity

Throughout this paper we attempted to reflect on the natural interaction between the socio-ecological and the socio-technical systems capable of combining, improving or blocking urban resources. Spatial heterogeneity has been addressed as a positive property of resilient urban environments. Still, the question remains as to whether spatial heterogeneity is against or in favor of both performance and resilience of urban sub-systems and what are the implications on urban environmental quality.

Urban planning has become a powerful tool to modify political, social and economic structures. Uncoordinated strategies between the systems that conform the urban space can lead to major failures in, for instance, legislation, social and political structures. This negotiation cannot start if urban strategies are subordinated to each other, destabilizing environmental and social consequences. Instead, the negotiation shall be directed toward the coproduction of landscape with stable socio-spatial conditions. Careful interaction and negotiation processes are persuaded with the vision of their capacity of coevolution.

The following paragraphs grasp this negotiation process from hypothetical cases.

For example, smaller plots with different building uses may generate heterogeneity. The fact of creating smaller plots increases the variability of land use, users, physical layout, spatial functions, among others. This will generate a loop in which spatial heterogeneity may bring more diversity. However, it may be difficult to set thresholds in terms of environmental stressors. In these cases, zoning will be fragmented as well as an answer to the performance needs (e.g. residential areas, services areas, etc.). Hereof, inaction in terms of air and noise pollution may be increased by the spatial decisions, generating a cascade effect. In contrast, homogeneity in urban planning processes, may neglect the complexity implied in the interaction of urban systems. The result might end in the lack of capacity to absorb challenges. Over long periods of time, this situation may lessen their ability to respond to changes, such as economic susceptibility in the form of housing depreciation due to the presence of noise and air pollution.

Two key elements of spatial heterogeneity are scale and boundary. These elements are combined in a manifold spectrum of objectives that society and individuals head for. Therefore, it is important to identify the scale according to the needs. In this regard, spatial heterogeneity does not necessarily imply functional characteristics of diversity affecting system performance, and vice versa. For instance, in a neighborhood scale, a spatially heterogeneous neighborhood can be mono-functional, thus having a very low degree of diversity (e.g. dormitory suburb with 'planned' diversity). Conversely, by changing the approach to a larger scale, a spatially homogeneous urban area can have high degrees of response diversity, influencing the resilience behavior (e.g. industrial warehouses converted into mixed-use developments, changes in building typology affecting mobility patterns).

The understanding of complexities in the built environment is essential to guarantee the livability of spaces. The fragmentation of urban processes added to the rapid pace in urban development condemns the built environment to become obsolete without adaptive capacity. The focus appears to be on the most urgent, with the risk of missing opportunities to improve the built environment quality. Urban planning processes demand a certain urban flexibility encompassing a holistic approach design. This approach requires the capacity to integrate the complexity attached to the natural interaction of urban systems, a sense-making methodology to improve livability of spaces.

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