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Towards a Spatial Morphology of Urban Social-Ecological Systems

Abstract:

The discussion on sustainable urban development is ubiquitous these days. Concerning the more specific field of urban design and urban morphology we can identify a movement from a first generation of research and practice, primarily addressing climate change, and a second generation, broadening the field to also encompass biodiversity. The two have quite different implications for urban design and urban morphology. The first, stressing the integration of more advanced technological systems to the urban fabric, such as energy and waste disposal systems, but more conspicuously, public and private transport systems, often leading to rather conventional design solutions albeit technologically enhanced.

The second generation ask for a more direct involvement of urban form, asking the question: how are future urban designs going to harbor not only social and economic systems, which they have always done, but ecological as well, that is, how are we in research on urban form, as support for future practice in urban design, develop knowledge that bridges the ancient dichotomy between human and ecological systems. This paper presents, firstly, a conceptual discussion on this topic, based in Resilience Theory and Urban Morphology, secondly, the layout of a principal research field towards a spatial morphology of urban social-ecological systems, where strategic research tasks are identified.

Keywords: Social-ecological systems, Sustainable urban development, Resilience theory, Urban morphology, Urban design, Institutional theory, Space syntax

1.1 From planet Earth to spaceship Earth

On 16 October 1967, at the 50th annual convention of the American Planner Association, the engineer, architect and futurist Buckminster Fuller delivered an address with the title An Operational Manual for Spaceship Earth. The message was that the Earth had become human-dominated to the degree that we should no longer talk about ourselves as living on planet Earth but spaceship Earth. Consequently, just as any spaceship the Earth was in need of proper human maintenance, hence the need of a manual (Fuller 1968).

While rich in the beliefs in human engineering typical of its time, the accuracy of Fuller's diagnosis has since become increasingly evident. Today there is no longer any doubt that we live in a human-dominated world. Many of the changes in the biosphere, including the modification of landscapes, loss of biodiversity and according to most scientists, climate change, are driven by human activities. These changes are, furthermore, occurring at a faster rate than previously experienced in human history. It has also to an increasingly degree become clear that social and ecological systems truly are interdependent and interconnected across spatial and temporal scales and could, hence, be referred to as *social-ecological systems* (Berkes et al. 1998; 2003). This is a conclusion that marks a historic breach of the man-nature dichotomy where these systems, at least conceptually, have been kept firmly apart in Western thought since the Enlightenment.

However, while our knowledge on the critical consequences of human domination of the Earth steadily increases, our knowledge on what to do about it does not as easily follow. We can describe the world and generate knowledge about its inner workings, but that does not carry in itself knowledge about how to change the world. A translation of theoretical knowledge into practical knowledge is necessary and a challenge in its own right. So, while we are increasingly realizing that we are travelling on a spaceship, we still do not have the means to write its manual.

1.2 The sciences of the artificial

A contemporary to Fuller of equal polymath dimensions is Herbert Simon, whose groundbreaking idea of the Sciences of the Artificial overlaps with Fuller's in many ways (Simon 1969). He makes the observation, which is so obvious once stated, that living in a world dominated by man made objects, we need *sciences of the artificial* to go along with the sciences of the natural. This idea has, among many things, evolved into Design Methodology, a field of knowledge dealing exactly with developing knowledge about the process behind the creation of man made objects (Alexander 1964; Schön 1983; Cross 1984, 2007; Lawson 2006)

The relevance of design, which Simon understands in a wide meaning, for translating theoretical knowledge into practical intervention, is manifold. First, even though we realize that the Earth from a human point of view increasingly has come to resemble a spaceship, for a successful manual of its operation we need to go from the metaphor to a more concrete understanding of the construction of this spaceship, that is, develop the concepts and theories that *present the Earth as a design*. The importance of this is that it is first with such a presentation it opens for informed intervention. Second, a science of making is something different from technology. In the end technological knowledge carries the same problems as theory in its need to be translated to be useful in practical application. The need to adapt particular technological solutions to its social, cultural and, not least, technological context is critical, thus, *to apply technology is in the end a design process*. Third, maintenance is not a static procedure repeated time after time but entails continuous development and adaption. This implies also a critique of the narrow almost utopian definition we have of design today as the creation of original objects never to change. In the face of current challenges a more modest approach seems appropriate, where continuous adaption is seen as a constituent part of maintenance, whereby *maintenance is nothing but a process of continuous design*.

In summary, on the one hand, we need to realize that the Earth has become a spaceship rather than a planet in the sense that we can no longer understand ourselves as being outside what we, for better words, can call Nature, but are intrinsically part of it. That is, the Earth we inhabit needs to be understood as a *social-ecological system* and we need to rapidly develop our knowledge on how this system operates. This leads, on the other hand, to the realization that we are left with the task of maintaining this spaceship and given the rapid development of our societies, this most likely implies a process of continuous development and adaption. We believe it is fruitful to understand this as a *design process*, where the knowledge that currently is being developing around the world on the Earth as a social-ecological system, needs to be fed in and met with other forms of knowledge, so that it can be translated and made useful in successful intervention and maintenance.

The research field we propose here is then not only an interdisciplinary field in that it on a fundamental level integrates social and ecological systems and aims to develop knowledge on their interaction, but also a transdisciplinary field, in that it want to move from knowledge to action by also developing knowledge that can inform professional practice.

2.1 Identifying the materials and media of urban intervention

The discussion above position such a research field in the middle of the huge domain of knowledge generally denominated *urban development*, these days almost by rule augment to read *sustainable urban development*. Cities are at the centre of contemporary debate on sustainable development both because they are the primary sources of global effects of the human domination of the planet, simply because we find the highest concentration of people in cities, and because the constitute they most artificial environments we have, which together make them the most effective targets for intervention.

However, entering the heterogeneous field of urban development, rich in both theoretical and practical knowledge, it is important and maybe even necessary to start by pointing to the fact that there would be cities and urban development in this world even if there was no professional intervention by planners or architects. More than anything, cities are prime examples of self-organising systems (Portugali 2000; Batty 2005; Miller & Page 2007), and furthermore self-organising systems of unusual complexity, comprising as they do different kinds of self-organising systems, such as social networks, economic markets and ecological systems, in interaction with each other. The point here is the fact that politically sanctioned and highly organised intervention, such as official urban planning and design, are interventions in ongoing processes that have an internal logic; that cities without urban planning and design do not lack order but present both highly developed structures and predictable processes, albeit not necessarily the structures and processes wished for.

Still, it is exactly such self-organising systems, and the rich and complex processes they represent, that is the target of organised intervention. We choose here to talk about such systems as the *material* in urban intervention, that is, the entities that one want to channel, structure and shape in politically sanctioned directions. It is obvious how one to be successful in such intervention needs a deep and rich knowledge about the inner logic of these systems and not least how they interact with each other. This is the most fundamental area of knowledge in the field of urban development, where the scientific foundations are found in a wide variety of major and well established disciplines such as Sociology, Economy and Ecology.

2.2 The media in urban intervention: space, institutions and discourse

If urban self-organising systems of different kinds constitutes the material in urban development, it must be stressed that to whatever degree we develop our knowledge about such systems, this does not in itself inform us on how to successfully intervene in them. This can seem a self-evident statement, but the failure to fully acknowledge this fact, accounts for a majority of the unsatisfactory results that has followed the history of modern urban planning and design. What we need to identify and develop knowledge on is, therefore, also the *media* we use for intervention in urban systems. No professional practice can act directly on any urban system, self-organising or not, but is confined to creating, structuring and maintaining conditions for these systems through particular media.

The most evident example is maybe found in *urban design*. The professional practice of urban design is exactly about trying to influence different self-organising systems in the city, for example pedestrian movement or the distribution of retail, by the structuring and shaping of *urban space* in a most tangible understanding of the word (e.g. Hillier & Hanson 1984). Characteristic for urban design is that this is accomplished using very concrete media such as the structuring and shaping of buildings and landscapes, that is, built form. Therefore we can conclude that urban space as structured and shaped by built form, is the characteristic medium used in urban design to intervene in different urban systems, and therefore also, that it is the medium the urban designer needs to master to be successful in her profession. For this to be possible we obviously need to develop knowledge on spatial systems of this kind, that is, we need to develop the field of *spatial morphology*. At the same time, while these intermediary systems do need proper knowledge development in themselves, it is knowledge on how they interact with and affect the kind of self-organising urban systems we have discussed above that is critical for successful intervention. Hence, the idea proposed here of a particular field of research concerned with the *spatial morphology of social-ecological systems*.

Similarly, other professional practices in urban development, such as *urban planning* or *urban governance*, are neither one able to directly influence urban processes, but are just like urban design directed to particular media to accomplish their objectives. Returning to urban space, while being the most tangible dimension of cities, it does not exist in isolation, but within a framework of rules and regulations, actors and agents, networks and local cultures, that is, a framework of formal and informal *institutions* (e.g. Ostrom 2001; Guy Peters 2005). In analogy with how urban space is used in urban design as a medium whereby one guides and directs urban processes, such institutions can be said to be the primary medium used in *urban planning* to guide and direct urban processes, keeping in mind, at the same time, the many overlaps between urban planning and urban design.

Finally, we need to acknowledge that both urban planning and urban design as interventions in urban processes are embedded in a sphere of policy and discourse in general, which set limits to both the range and effect of these professional practices. The impact of such discourse on both human mind sets and behaviour should not be underestimated and there is today a rich flora of approaches to discourse analysis (e.g. Jörgensen & Phillips). In analogy with our earlier discussion, discourse can be said to be the prime medium, while arguably also incorporating space and institutions, for the last form of urban intervention to be discussed here, that is, *urban governance*. We can then talk about a third medium of urban intervention, that is, *discursive systems*, this time a medium most characteristic for the particular form of urban development called urban governance, albeit also found within the others.

2.3 An emerging model of urban planning and design as a field of intervention

Summarising the discussion, we can identify a set of media at different levels of urban intervention, fitted together in a nested hierarchy like boxes within boxes. It seems like the correct description here is a *hierarchy of embeddings*, where spatial systems are embedded in institutional systems, which in turn are embedded in discursive systems, keeping in mind that there also are a lot of interconnections, overlaps and feed-back loops. These systems can all be linked to different professional practises aimed at guiding and governing urban processes in accordance with political objectives. Taken together, we start to see the contours of a model for urban development as a field of both knowledge and practice (Fig. 1).

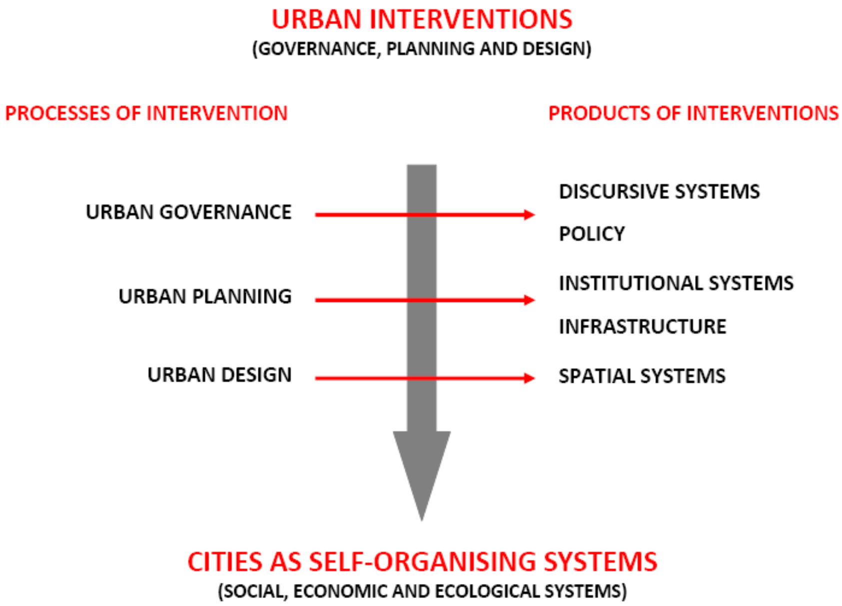

Fig. 1. A model for the field of knowledge and practice in urban development, identifying strategic areas of research.

This emerging model help us see, on the one hand, how we need proper knowledge on cities as self-organising systems, such as social networks, economic markets and ecological systems, and, not least, their interaction as social-ecological systems, which help us understand the inner logic of their functioning. This represents an interdisciplinary knowledge challenge. But this would not suffice to inform professional practice in the field. We therefore, on the other hand, also need proper knowledge on the inner logic of the systems we use as media in different professional practices, such as discursive, institutional and spatial systems, and, more precisely, their effects on different urban processes. This represents a transdisciplinary knowledge challenge.

In the following we will present more in depth two theoretical fields in strong development that we believe together are most apposite to address the two knowledge challenges identified above. These fields are, on the one hand, *social-ecological systems as developed in Resilience theory* (Holling 1973; Berkes et al. 2003; Gunderson et al. 2010) and, on the other hand, *spatial morphology as developed in Space syntax theory* (Hillier & Hanson 1984; Hillier 1996; Koch et al. 2009).

3.1 Resilience theory: the nonlinear dynamics of ecosystems

Canadian ecologist C.S. Holling (1973) introduced the concept of resilience in ecological research as a way to understand nonlinear dynamics in natural systems, such as the processes by which ecosystems maintain themselves in face of disturbance and change. By *resilience* is here meant the capacity to buffer and encapsulate disturbance so that it does not become fatal and destroys the system's basic features and functions, or the amount of change the system can undergo and still retain the same functions and structures, i.e. remaining in the same domain of attraction (Holling 1986).

Holling developed the theoretical foundations of a resilience management of ecosystems and natural resources as a reaction to the "command and control" management that had characterized conventional resource management systems for decades (Holling and Meffe 1996). Such management systems had a strong sector-based focus, often aiming at managing a few target resources, e.g., timber, monoculture crops, fish species, or livestock that were primarily managed for economic output without consideration of the consequences such management had on the ecosystems they were part of (Regier and Baskerville 1986). Holling (1986) argued that badly adopted nature-social interdependencies lead to increasingly brittle ecosystems that over time lost the capacity to buffer and incorporate natural perturbations (Colding 2001). The realization that natural disturbances (e.g., storms, fires, droughts) are an inherent part of the renewal of natural systems (or, ecosystems), and a prerequisite for maintaining biological diversity in them, made Holling conclude that command and control management rather invited larger-scale disturbances to enter the system and to accumulate over time; hence lead to management surprises and unanticipated shocks and to that systems became unmanageable.

To manage a system for resilience involves maintaining the capacity of the system to change. In social terms, it involves having flexible institutions that are capable of addressing change and respond to novel phenomena and keeping a multitude of options open for adequately dealing with change. Applying a resilience lens to systems means that *sustainability* is seen rather as a process than an end product, a dynamic process that requires adaptive capacity in order to constantly deal with change in active ways (Berkes et al. 2003).

3.2 Social-ecological systems: bridging the man-nature dichotomy

Since the Age of Enlightenment, the separation of nature and society became a foundational principle of Western thought and provided the organizational structure for academic departments (Davidson-Hunt and Berkes 2003). However, since then, models of natural system-society articulations have been plentiful in the literature and spanning many disciplines (e.g. Ingold 1980; Harvey 1996). Examples include human ecology (Park 1936), cultural ecology (Steward 1955), the ideas of Carl Sauer (1956) and other human geographers (see more examples in Davidson-Hunt and Berkes 2003). However, with the increasing environmental problems that mankind presently is facing and our lagging ability to solve them, it has increasingly become clear that social and ecological systems truly are interdependent and interconnected across spatial and temporal scales; hence, can be referred to as *social-ecological systems* (Berkes et al. 1998; 2003).

It is now clear that the separation between human and natural systems is a human construct that has had immense impact in shaping mental worldviews, hampering the development of a fuller understanding on the human condition. Such a dichotomy is evident for example in land-use classifications, which influence urban planning and design (Colding et al. 2006). On another level it relates to the increasing 'environmental generational amnesia' characterizing city dwellers (Miller 2005) that in turn affects policies on environmental problems inside and outside cities (Kaplan et al. 1998). The classification of landscapes into urban and rural systems, furthermore, hampers a deeper understanding of human settlements. In reality, there exists an intense interplay with reciprocal flows and influences between cities and their rural surroundings, which, has increased tremendously during the last century. This calls for an open definition of urban systems (Pickett et al. 2001) that also accounts for the urban-rural continuum and creates the necessary foundation for the development of knowledge that can support our ability to build sustainability.

3.3 Ecosystem services: putting urban ecosystems in a socio-economic framework

A concept that may be particularly promising for more fully integrate ecological and socio-economic functions in urban form and design is *ecosystem services*. Paul Ehrlich first coined the concept in the 1980s, but it was not until the mid 1990s that it became more widely used and developed within the field of ecological economics (see e.g., Daily 1997). A further ten years passed until attempts were made to link it to urban green space and land use (e.g. Colding et al. 2006; Barthel et al. 2005; Andersson et al. 2007) and more specifically to urban spatial planning (Colding 2007; Colding 2011). Ecosystem services refer to all the services that natural systems supply to humans such as foods, fibers, biological diversity, clean water and air, treatment of human induced waste and pollution, the regulation of regional and local climate, and protection from natural hazards. Such services can further be grouped in four distinct categories, including *provisioning services* (the services required to generate products obtained from ecosystems like food and fibers); *regulating services* (the benefits obtained from the regulation of ecosystem processes like air- and water filtration); *cultural services* (the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences); and the *supporting services* (those that are necessary for the production of all other ecosystem services including functioning nutrient- and water cycles) (MA 2005).

A good example of the socio-economic value of ecosystem services is the pollination service performed by honeybees on agricultural crops in the EU, and which annually amounts to 30-40 billion USD. If this “free” service is lost, it will have tremendous impacts on the price for food since pollination instead needs to be conducted through human hands. To plan for ecosystem services as cities develop is also important in order to make cities more resilient in buffering effects from changing climate, such as heat waves, droughts, or increased flooding. As ecological research demonstrates, green areas in cities like parks, greenways, golf courses, allotment areas, gardens and so forth contribute positively in generating a multitude of desirable ecosystem services (Colding et al. 2006). Few people are aware of that, for example, it is about 85% less air pollution in a park relative a built-up area in a city, or that it is 75% less air pollution in a street with tress than a street lacking trees (Bernatzky 1983). Green infrastructure in cities can also sequester a huge amount of carbon dioxide emitted from traffic. In the city of Stockholm, for example, as much as 40% of such emissions can be sequestered and purified by the city’s green wedge system (Jansson och Nohrstedt 2001).

Ecosystem services (ESS) are diminishing globally with 60% being degraded or used unsustainably (MA 2005), and with cities appropriating a disproportionally high rate of such services (Brown et al. 2001). Studies show that the changes being made in ecosystems are likely to induce nonlinear changes in human societies (including accelerating, abrupt, and potentially irreversible changes), threatening the resilience of life-supporting systems with consequences for human well being and economic viability (MA 2005). In this light, it is not an oxymoron to foresee that international conventions will need to be developed for cities to manage ecosystem services in cities in the near future, something that would presuppose a spatial morphology of urban social-ecological systems.

4.1 Urban space: descriptive traditions

There are two major traditions of descriptions and analysis of urban space, both with their roots in Geography. On the one hand *spatial modeling* (Wilson 2001), with its origin in analysis of land uses and land values by von Thunen (1826) which were later developed into more advanced and influential models, especially Walter Christaller’s Central Place Theory (1933) and its parallel developed by Losch (1940). With the development of modern computers, this tradition has been augmented in a dramatic way in recent decades, both in the form of GIS, which has led to a revolution in the power of geographic description and data-processing (e.g. Longley & Batty, 2003), but also more advanced forms of spatial modelling, like cellular automata and agent based modelling (e.g. Batty 2005).

On the other hand, we have *urban morphology* (e.g. Vernez Moudon 1997), evolving out of its three major schools, the English with its origin in the micro-scale geography of settlements and the subsequent development of Town-Plan Analysis (e.g. Conzen 1969; Whitehand 2001); the French, where the analysis of land division and cadastres has been central in research on the relation between space and society (e.g. Panerai et al. 1980); and the Italian, with its origin in historic description of building types and the idea of an Operational History as support for new development (Muratori 1959,1963; Caniggia 1979), also spilling over to architectural theory (Rossi 1966). The general approach that all schools have in common, that is, developing typologies of urban form at different scales, also come close to how urban form primarily has been dealt with in architecture, both academically (e.g. Kostof 1992, 1993) and in practice (e.g. Duany et al. 2000, 2003).

While spatial modelling recently has seen rapid development, it has almost completely been concerned with analysis of aggregated levels of urban systems (Batty 2005). This is in part due to the difficulties of gathering fine scale data, but more importantly, to the difficulties of relevant modelling of urban space at a finer scale. There is therefore agreement that knowledge on how to model, what can be called *the cognitive level of urban space*, that is, the level where the city is experienced by 'people in the street', is underdeveloped. Urban geographers (Emily Talen 2003), spatial analysts (Mei-Po Kwan 2003) and urban morphologists (Bill Hillier 2006), independently point out the lack of knowledge on this scale of urban space. Current knowledge development, dominantly based on aggregated data and low spatial resolution, is therefore deemed unsatisfactory for theoretical advancement of the field (Batty 2008).

4.2 Space syntax: the configurative analysis of urban space

Many of these difficulties are directly addressed by the research tradition known as *space syntax*, where an analytical approach is taken to the cognitive level of urban space, specifically aiming at knowledge supporting architectural and urban design (Hillier and Hanson 1984; Hillier 1996). As a matter of fact, space syntax can be described as an approach that draws from both of the traditions described above. Sustaining the system perspective of spatial modelling but adding more imaginative geometric description from urban morphology, it merges the previous traditions into an analytical urban morphology, focusing space. Hence the understanding on our part of space syntax, as an original and successful school within a wider and to a large extent undeveloped research field, suitably called *spatial morphology*.

Instrumental for space syntax analysis is the invention of the *axial map*, which is a representation of urban space, as structured by urban form, from the point of view of a cognitive subject, that is, an experiencing and acting human being. The axial map is made up of the least amount of straight lines that cover all accessible urban space in the area of analysis, where each straight line (here called axial line) in the map represents an urban space that is possible to visually overlook and physically access (Fig. 3). Thus, the axial map, through quite simple geometry, captures both phenomenological aspects of being in urban space, through the individual axial lines, and systemic aspects of urban space, through their configuration in the complete axial map (Seamon, 1994). This forms the basic geometric representation on which different calculation can be made, for example, the topological accessibility of each and every axial line from each and every other axial line in the map, which measures what is called the *integration value* of each line. Analysis of this kind have proven, in a long series of studies around the world, that there is strong correlation between such integration values and pedestrian movement, that is, a most generic aspect of urban life (Hillier et al. 1993).

Figure 2. Urban space as structured and shaped by urban form in a city district in Stockholm (left), and the axial map of the same area (right).

In extension of this fundamental relation a large body of research (e.g. Koch et al. 2009) have found correlations between urban form and other urban phenomena, where movement often work as the intermediary. It is, for example, not surprising to find that streets that are well integrated in the street system and therefore collect a lot of movement also become prominent locations for retail. This has also been confirmed in many studies (e.g. Cutini 2001; Ståhle et al 2011). Taking this a step further, it also seems likely that such streets in the long run may gather higher rents for the letting of floor-space. Also this has been confirmed (e.g. DeSyllas 2000; Netzell 2010). Other studies show similar patterns between urban form and urban phenomena, for example, crime (Hillier & Xu, 2004); social segregation (Vaughan et al, 2005; Legeby 2010); conceived accessibility to green spaces (Ståhle 2005).

Fig. 3. The distribution of spatial integration, correlating in this case with observed pedestrian movement by 70% (R2=0.70)

Space syntax research has thus broken new ground and specifically opened up the challenging cognitive level of urban space for analysis and knowledge development. This is of essential importance in two ways for the proposed field in this paper. First, the possibility to model and analyse the cognitive level of urban space is strategic for the further development of our understanding of cities as complex self-organising systems. Second, by developing knowledge on this level of urban space, one is exactly developing knowledge on one of the intermediary systems discussed above, that is, urban space as structured and shaped by urban design.

4.3 Spatial capital: towards an analytical theory on sustainable urban form

As underlined earlier, we understand space syntax neither as a complete research field in itself or a mere sub-division of urban morphology in general, but as a formative and successful school in a new and promising field of research that it originates but does not exhaust. We prefer to call this field *spatial morphology* and see it as characterised by a successful combination of the complex system perspectives of modern spatial modelling and imaginative geometric descriptions drawing from both urban morphology and architectural theory.

In sympathy with such an understanding, research aiming to expand space syntax research into the wider field of spatial morphology, has been undertaken at KTH School of Architecture over a ten year period. This work has proceeded along two lines. First, there is a strand developing analytical tools and empirical studies that incorporates geographical data into the purely geometric analyses characteristic for space syntax (Ståhle 2005; Ståhle et al. 2006; Koch 2007; Markhede & Miranda 2010). Second, there is a strand developing new geometric description and measures aiming to capture other spatial variables than what has traditionally been done in space syntax research (Marcus 2000; Marcus 2001; Marcus 2008; Ståhle 2008; Koch & Markhede 2010). Paired with empirical studies investigating the influence of urban form in different urban themes, such as, Social cohesion (Marcus 2007; Legeby 2010, Legeby & Marcus 2011); Economic markets (Sardari Sayyar 2010; Ståhle et al. 2011); Environmental ecology

(Ståhle 2005, 2008; Marcus et al. 2010); Knowledge environments (Steen 2005; Steen & Koch 2009; Bergström et al. 2010); Walkability and health (Choi & Koch 2010), these methodological developments are currently developed and synthesised into a theoretical framework called Spatial Capital (Marcus 2008; Marcus 2010; Marcus in progress).

The point of departure is the development of pertinent geometric descriptions of urban form. In the context of spatial capital, three fundamental geometric variables in urban form have been identified (Marcus 2008, 2010). First, *density*, that is, the possibility to enhance urban space through built form by adding floor space on top of each other. Second, *diversity*, that is, the possibility to enhance urban space through built form by dividing it into additional spaces. Third, *accessibility*, that is, the possibility to structure urban space through built form by creating particular configurative relations between spaces. In relation to the need to develop descriptive models of the cognitive level of urban space earlier stressed, it should be underlined how the measures of both density and diversity in the context of spatial capital are measured as *accessible density* and *accessible diversity*, thereby transforming these normally aggregated measures into cognitive descriptions (Ståhle et al. 2006; Marcus 2008; Marcus in progress).

4. Integrating the two: an outline of a spatial morphology of resilience

From the reviews above it is clear that what we are looking for is not only the spatial means to support social-ecological systems but resilient social-ecological systems, why we in the development of a spatial morphology of social-ecological systems first need to identify the morphological properties of resilience. Of particular interest for such an endeavour is how certain critical attributes can be identified as typical for resilient systems. This is supported by a number of empirical case studies on enduring social-ecological systems around the world (Berkes et al. 1998; 2003). While these attributes must be regarded as tentative and in need of further enquiry, four such attributes seem strikingly reoccurring. These are: *disturbance*, *diversity*, *self-organisation* and *learning*. In the following there will be a first introduction of each attribute and its function in developing resilience in social-ecological systems, followed by an interpretation of these attributes and their function, using the spatial variables introduced above, that is, a first step towards developing a spatial morphology of resilient systems.

4.1 Disturbance

Fundamental for resilience theory is the idea that change, surprise and crisis are inherent characteristics of all complex, adaptive systems (Levins 1999). *Disturbance*, in this sense, is not a threat but a natural and necessary opportunity for renewal and novelty for both social and ecological systems. At the same time, the scale and magnitude of disturbance together with the inherent resilience of the system determines to what degree a system is capable of self-repairing. So disturbance is here in a way part of the remedy to its own threat. Therefore, the interplay of disturbance and resilience in a system for surviving change and perturbation is of central importance to account for in the design, management and governing of social-ecological systems (Berkes et al. 2003).

Acknowledging the problematic question about how to delimit a system, we can in general terms still say that disturbance can either come internally or externally of an urban system. In terms of the spatial morphology of cities, external disturbance is clearly related to the degree an urban system is spatially connected to surrounding systems, also at quite great distances, and the potential the system has of receiving input of different kinds, be it in the form of new information, people or biota. We can talk about to what degree a city is an open or a closed system, implying the dual meaning that a greater openness also means a greater complexity. In general terms we could talk about the importance of *global accessibility* in a system when it comes to building resilience through external disturbance.

Disturbance from within seems in a similar way to have to do with the connectedness of different parts within the system so that new constellations of information, people and biota can give rise to change and innovation that can renew the system. We could therefore in the same general terms speak of the importance of *local accessibility* as a means to open up for disturbance from within. In summary, the attribute of disturbance in resilient systems, seems in spatial terms intrinsically connected to the variable of accessibility at different scales.

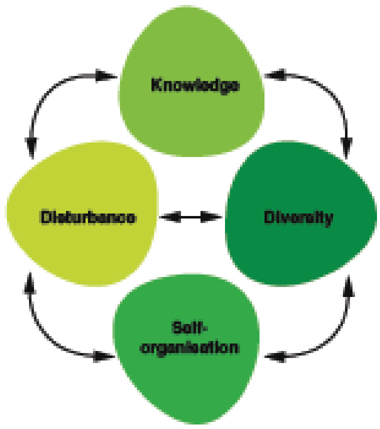

Fig 3, Disturbance, Learning, Diversity and Self-organisation as critical attributes of resilient systems

4.2 Diversity

A second attribute of fundamental importance for resilience in a system is *diversity*. Diversity spreads risks, creates buffers, and opens for multiple strategies from which to learn when uncertainty is high. In addition to functioning as insurance, diversity also plays an important role in the reorganization and renewal process following disturbance or events that create change in social-ecological systems, by creating a frame for creativity and adaptive capacity to reorganize and survive perturbation (Berkes et al. 2003).

In the spatial terminology we want to introduce here, diversity is directly connected to the concept of *spatial capacity* (Marcus 2008), that is, the creation of multiple spaces, which can harbour, support and develop differences in information, people and biota. The idea is simply that for diversity to develop, one entity needs a space distinct from another, both as a means to conserve its difference but also as a means to develop it further. When talking about the need for allowing disturbance through global and local accessibility above, it was implied that this meant accessibility to something different. But neither global nor local accessibility necessarily means accessibility to difference in itself, it must be catered for by creating spaces that can support and develop diversity, that is, one needs to create spatial capacity. We can then start to see the contours of an emerging network of distinct spaces carrying difference that, depending on the particular network, to varying degrees are made accessible to each other.

4.3 Self-organisation

The capacity to respond to and shape change in productive ways is a key attribute of *self-organization*. For example, social systems that have the ability to respond to change and reorganize in constructive ways are likely to have flexible institutions (i.e. rules and norms) that allow for adaptation to changing circumstances (Ostrom 1990), and a social organization that allows for knowledge exchange among different stakeholders and actors so that appropriate responses to changing conditions are facilitated and cultural inertia avoided (Colding & Folke 2001).

In spatial terms, this is more or less what we have already described with the emergent network of distinct spaces of difference and their varying accessibility to each other. In such a network differences can connect to each other in various configurations in response to different types of disturbances. But this is only the spatial preconditions for a self-organising system, the degree to which a system allows for self-organisation has to do with the particular configuration of this network. Here we can speak of a range from high generality to high specificity in the network, where a higher degree of specificity is created by decreasing both the general accessibility in the system and its capacity to carry differences (Marcus 2000). In most general terms we can, furthermore, say that a higher degree of specificity in the system restricts the allowance for self-organisation, while a higher degree of generality works in the opposite way. This obviously runs the risk of simplification but it serves the purpose to introduce the fact that such a network could be an object of design and possible to adjust to fit a specific context.

4.4 Learning

Finally, the capacity in a system for *learning* is an essential attribute in building resilience. For human systems this implies knowledge in many forms and on many things but on a more generic level that can include ecological systems we need to understand the idea of learning for example in the sense of memory, that is, the ability of the system to retrieve lost information after disturbance, damage or loss. For example, reconstruct damaged eco-systems from pockets of unharmed habitats and species after forest fires.

In spatial terms this again points to the fundamental role of our basic network of connections and spaces that carry difference, where such spaces can work as pockets of survival in crisis from which the system can be retrieved if the right connections are there. But this stays very close to the faculty of self-organization. To be able to talk about memory and even learning, we need to once again stress the great variety of configurations such a basic network can take. While the spaces of difference and the connections that make them accessible to each other, form the basic material, it is the specific configuration typical for a particular ecological or social system, or a combination of the two, that carry memory and even knowledge. The particularity of the design of the system becomes a form of writing, that can carry memory of the particular properties of the system and even carry knowledge about it specificities and unique adaption to a particular context.

5. Cities as resilient systems: the need of a spatial morphology

In many ways the description above is nothing but a description of any system or network, resilient or not. But this is not a weakness for the current discussion but a strength, and that in two prominent ways. First, it is through the fact that these fundamental attributes of resilience can be shown to have a most distinctive spatial dimension, which can be translated into a generic network model, that these attributes can become an object of design, that is, it brings them within reach of informed human intervention. In short, it opens for the possibility to develop knowledge on how to design resilient systems in general. Second, the generic character of the model makes it very easy to translate to different types of systems. So far we have taken general attributes of resilient social and ecological systems as our point of departure, and shown how they in principle can be translated into a spatial model. Having done that it is obvious how this model resembles the largest man made spatial systems we have, that is, the spatial systems of cities. We can thereby, on the one hand, use our model to discuss or evaluate the degree of resilience in different urban systems and, on the other hand, use it for informed intervention to support or increase the resilience of such a system. In short, it opens for the possibility to develop knowledge on how to specifically design resilient *urban* systems.

However, this is only scratching the surface. To be able to proceed and develop a truly informed resilient social-ecological urban design, we need a lot of new knowledge, hence our argument for a new research field aiming at a spatial morphology or urban social-ecological systems. Referring to our earlier model of spatial intervention (fig. 1), we see three primary and strategic areas of research for the development of resilient urban systems. First, the area of spatial systems and the need to develop a spatial morphology that can inform urban design in key attributes of resilient systems. Second, the area of institutional systems, where there is a need to understand the institutional embedding of spatial form, with the aim to develop institutional support for urban design of resilient urban systems. Third, the area of discursive systems, where there is an urgent need for critical analysis of many fundamental concepts and assumption in current sustainability discourse, once again, with the aim to support urban design of resilient social-ecological urban systems, but now on a discursive level. Together we believe this to be a major contribution to the development of an operational manual for space ship Earth, keeping in mind the lessons of humility the decades since Fuller made his address has taught us about such human endeavours.

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