What makes cities complex?

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The city as a complex artifact

In 1943 Nobel Laurent (1933) Erwin Schrödinger gave a lecture at Trinity College Dublin entitled *what is life;* a year later "what is life" was published as a book (Schrödinger 1944). In it Schrödiner answers the question by reference to entropy: mater is subject to the second law of thermodynamics, that is, to the process of entropy, while life entails a dilemma:

> "How would we express the marvelous faculty of a living organism, by which it delays the decay into thermodynamical equilibrium (death)?"

His answer is that by means of the process of metabolism a living organism

> "… feeds upon negative entropy, attracting … a stream of negative entropy upon itself, to compensate the entropy increase it produces by living and thus to maintain itself on a stationary and fairly low entropy level."

This notion of negative entropy was later termed *negentropy* (Brillouin 1953).

Schrödinger's view of life and his suggestion that "Organization is maintained by extracting 'order' from the environment" in fact anticipated the notion of *order out of chaos* that has become *the* motto of complexity theory. And indeed, three decades later, in December 8, 1977, Ilia Prigogine (1977) in his Nobel lecture demonstrated that in certain circumstances matter too behave as if it has life; and so he said:

> The classical formulation [of entropy] due to Clausius refers to isolated systems exchanging neither energy nor matter with the outside world. […]. It is easy to extend this formulation to systems which exchange energy and matter with the outside world. (see fig. 2.1). We have then to distinguish in the entropy change dS two terms: the first, deS is the transfer of entropy across the boundaries of the system, and the second diS, is the entropy produced within the system. … (ibid, p 264-5)

Prigogine termed his theory of complexity *dissipative structures.* More or less in the same time Hermann Haken (1987) developed his theory of complexity that he termed *synergetics* while Lorenz (1963) developed the theory of *chaos*; a few year later Mandelbrot (1983) developed his *fractal geometry*, Bak (1996) his *self-organized criticality*, and recently *the new science of networks* was introduced by people such as Barabasi (2002) and Watts (2004). While all the above refer to open and complex systems in far from equilibrium conditions, each of these theories emphasizes specific aspects of complexity.

The link to towns and cities accompanied complexity theory from the start. Thus in his Nobel lecture Prigogine (1977) writes:

> Are most types of 'organizations' around us of this nature?", [that is, characterized by thermodynamic equilibrium?]. […] the answer is negative. Obviously in a town, in a living system, we have a quite different type of functional order. To obtain a thermodynamic theory for this type of structure we have to show that non-equilibrium may be a source of order.

This usage of the city as a metaphor of complexity appears time and again in Prigogine's further writings. However, it was Peter Allen who first developed a complexity theory of cities (Allen and Sanglier (1981) and by so doing he opened the domain of CTC – *complexity theories of cities*. Developed by a small but active community of researchers studies in the domain of CTC have demonstrated that cities as open and complex systems exhibit all the properties of natural complex systems: they are open, complex, bottom-up and are often chaotic. They further have shown that many of the mathematical formalisms and models developed to study material and organic complex systems apply also to cities. In fact, many in the community of CTC were and still are, physicists or mathematicians running their models on data about cities.

Similarly to the grand complexity theories, each complexity theory of cities shed light on different complexity properties of cities: Thus, *dissipative cities* emphasis the link to the environment, *synergetic cities* the bottom-up interaction between the urban agents, *fractal cities* the fractal structure and morphology of cities, and so on. [For detailed reviews see Batty 2005; Portugali 2011].

But there is a dilemma in the current state of CTC for cities are artifacts: A city is a large scale artificial built environment composed of smaller scale artifacts such as buildings, roads, bridges … each of which is composed of still smaller artifacts and so on; and, artifacts are essentially simple systems. They might be very complicated such as supper computers but essentially they are simple system: buildings, roads or bridges, as well as neighborhoods, cities or metropoles do not interact with their environment or among themselves. So what is it that makes the simple system and artifact 'city' a complex system?

Cities as dually complex systems

The answer to the above dilemma is that cities are *dual complex systems* in four respects: Firstly, cities are composed of material components and human components. As a set of material components alone, the city is an artifact and as such a simple system; as a set of human components – the urban agents – the city is a complex system. It is the urban agents that by means of their interaction – among themselves, with the city's material components and with the environment – transform the artifact city into the complex artificial system city.

Secondly, as a complex artificial system the city emerges out of the interactional activities of its agents, but once it emerges, it affects ("enslaves", in the language of synergetics) the behavior of its agents and so on in circular causality. The city in this respect is a *complex artificial environment* (Portugali 2011, Chap 11). Furthermore, because of its size, the city is a large-scale collective and complex artifact that on the one hand interacts with its environment, while on the other it is an environment for the millions of people that live and act in cities.

Thirdly however, artifacts are not just the outcome of human interaction; rather they are also *the media of interaction*: The process involves, on the one hand, internal representations in the form of ideas, intentions, memories thoughts that originate and reside in the mind/brain of urban agents, while on the other, external representations, that is to say artifacts such as texts, cities, buildings or roads that reside in the world. Exactly as artifacts cannot directly interact among themselves, so also ideas, thoughts, intentions, plans and other internal representations cannot. They interact by means of the externally represented artifacts; be they texts, clothes … buildings, neighborhoods and whole cities and metropoles. The notion of SIRN came to capture this interaction between internal and external representations (ibid Chap. 7).

Fourthly, the city is a *dual complex system* also in the sense that the city as a whole is a complex system and each of its agents is also a complex system. The implication is that we have to include the cognitive capability of the urban agents in the dynamics of cities. *Complexity, Cognition and the City* (Portugali 2011) was a first attempt in this direction. In our more recent studies we show that the complex parts of the city – the urban agents – are parts of a special kind: they are typified by *chronesthesia* that is, the ability to mentally travel in time; back to the past and forward to the future.

Chronesthesia and the city

The notion *Chronesthesia*, known also as *mental time travel* (MTT), originally hypothesized by Endel Tulving (1983) with respect to episodic memory, refers to the brain's ability to think about (e.g. travel to) the past, present, and future. The notion is associated with several domains of cognition. One such domain is *cognitive planning* that studies the cognitive ability of humans to think ahead to the future and to act ahead toward the future. A second domain concerns studies of *prospective memory* that explore human ability to remember to perform an intended or planned action (Haken and Portugali 2005). A third domain concerns cognitive processes that support *episodic simulation of future events* (Schachter et al 2008). Recent neurological studies further indicate (Nyberg et al 2010) that certain regions in the brain "were activated differently when the subjects thought about the past and future compared with the present. *Notably, brain activity was very similar for thinking about all of the non-present times (the imagined past, real past, and imagined future)*." "These processes together", write Schachter et al (2008), "comprise what we have termed "the prospective brain," whose primary function is to use past experiences to anticipate future events."

The suggestion here is, firstly, that the planning and design of artifacts are direct manifestations of humans' chronesthetic memory. Humans are, in this respect, natural planners and designers. Secondly, that not only humans have the ability to, and are thus capable of MTT, but that they *cannot not* mentally travel in time – back to the past as well as forward to the future. This includes also urban agents – they too are natural planners and designers and as such cannot not plan or design.[1] These two suggestions shed light on two properties of cities: one that concerns the urban planners and designers vs. the urban planned and designed and the second, the nature of the urban landscape.

The planners and designers vs. the planned and designed

If urban agents are natural planners and designers, what are we to do with the prevalent distinction between the professional city planners and designers and the rest of the city's inhabitants? Theories of urbanism, planning and design as developed since early 20th century tend to treat planning and design as external interventions in an otherwise spontaneous urban process. The structure of cities, according to this view, is seen as an outcome of bottom-up spontaneous processes, on the one hand, and top-down planning and design interventions, on the other. Notions such as "organic cities" or "un-planned cities" thus refer to exceptions that in fact prove the rule. This is so also with CTC. Here too, a central question is how to plan and design cities in light of their nature as bottom-up self-organizing systems.

Our own studies about the complexity of cities in relations to planning and design entail a somewhat different view, namely, that due to nonlinearities that typify cities, the action of a single urban agent (e.g. an inhabitant) often influences the city more than the action of the formal city planners (e.g. the city's planning team). Taken in conjunction with what has been said above – that urban agents are natural planner/ designers – each urban agent is seen as a planner at a certain scale, and, that due to the property of nonlinearity that characterizes the city as a complex system, it is often the case that the planning or design action of a single non-professional urban agent/ planner/ designer dominates the city much more that the plans and designs of the professional planners. [For further discussion and examples see Portugali 2011, Chap. 15].

Planning and design behavior

Often the various cognitive capabilities are associated with distinct forms of behavior. For example, the ability of animals and humans to construct cognitive maps is described as *cognitive mapping*, while their related ability to find their way – *way finding behavior* (Golledge 1999). In a similar way, it has been hypothesized (Portugali 2011) that the various cognitive planning and design capabilities of humans entail a distinct form of behavior that might be called *planning behavior* and *design behavior*.

The above leads to a new view of the city and the urban landscape: From the perceptive perspective of the urban agents the city is to a large extent a landscape of plans, expectations, that is, of entities that doesn't yet exist (similarly to the stock exchange). As a consequence, a lot of agents' behavior and action in cities is determined not by response to the present situation in the city, but by plans that are not yet, and might never be, materialized, that is, by what the agents expect, plan or intend to do.

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[1] Obviously not all human action and behavior is planned and we thus need to distinguish between *planned behaviors* vs. *un-planned behaviors*.

Toward a unified field of study

The answer to the question posed in the title of the paper is that it is the urban agents with their specific cognitive capabilities (as mental time travelers and thus natural planners and designers) that make cities complex, or rather, dually complex environments. This conjunction between complexity, cognition, planning and design as discussed above indicates a potential for the emergence of a new field of study in which planning and design are not external interventions in an otherwise spontaneous and complex urban process, but rather integral elements in its dynamics.

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