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Towards A New Complex Science of Cities

What complexity science tells us about urban systems

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ABSTRACT

With most of the world population living in cities, there is an increasing complexity that is accompanying this process. In addition to the growing number of agents interfering in the planning process and in cities evolution, it is important to note that until today urban policy fails to understand its dynamics. Complexity sciences offers an open system methodology to approach urban systems. However, it is not a recent trend, but it has taken time to be part of the urban planning process.

Complexity sciences are based on a wide range of approaches that aim to reflect back our understanding of the world. In this paper we intend to set the grounds for discussion about a new emerging city science based on complexity sciences methods.

Context and background

This paper will explore the contribution of complexity sciences in city sciences. It starts by defining complexity sciences and tracing the evolution of urban theories until nowadays. It argues that a new science of cities based on complexity is required to understand urban systems and be able to guide urban policy choices. In fact complexity sciences applied to urban studies has challenged many misconceptions and generated counterintuitive assumptions that has helped build a new understanding of cities dynamics

Goal and Objectives:

This contribution is aimed at setting a common ground for urban planning professionals and academics about complexity sciences to set a debate on the importance of opening cities to complexity sciences.

Methodology:

In this paper we review the evolution of urban planning theories and trends chronologically and identify the tendency towards complexity. We then define complexity sciences based on reviewing main contributions in the field and end by presenting examples and applications of complexity sciences in understanding urban phenomena.

Results:

Major findings include the eminence of shifting our approach to urban planning from a reductionist point of view to a transdisciplinary approach that is based on system thinking and oriented towards complexity sciences.

Keywords :

Cities, Complexity Sciences, Urban Theory, System Thinking, Urban Dynamics

1. INTRODUCTION

We live in an age of exceeding complexity (Morin, 2005), and cities as one of the most elaborate human innovations are following this trend. This complexity doesn't stem from the growing sizes of cities, although it contributes to it, but it's rather from the diversity of interactions and agents in cities. It begins with what Le Corbusier described as the utmost objective of cities and striking a balance between the personal and communal life. (Corbusier, 1957)

However, until today no administrative urban framework, nor technological advance has successfully achieved it, we are still far from building liveable and sustainable cities. (Luís M. A. Bettencourt & Gonzales, 2016) Part of the issue is that cities challenge and defy our definitions and are constantly changing charged with specific historical meaning in a sense that any attempt made to reduce the complexities in cities only hampers our understanding of their dynamic.(Sassen, 2010)

In fact, the classical obsession with reductionism fails short of delivering a comprehensive idea about cities and how they work. Instead, complexity sciences offer a unique opportunity to sustain an extended and full view on cities. Complexity systems science's approach is not a new one, but it encourages transdisciplinary thinking, using models and tools from different disciplines to study complex systems. (Miller & Page, 2007)

Thanks to the availability of data in cities and the increasing power of computation, cities could be approached and studied through the lens of complexity sciences. Although, computation facilitates these studies, it is not a required tool. The objective is not to develop tools based on complexity sciences for smart cities(Opromolla & Volpi, 2020), but rather use tools and models that make us think smarter about cities.

The approach presented in this paper is oriented towards understanding the evolution of city sciences and the resurgence at the age of information of new tools and methods that are changing the way we think about cities.

Although cities as an object of science is not a new idea, seeking a unified theory that explains urban systems dynamics is an opportunity to go beyond simple urban theory to simulation and studying cities as complex adaptive urban systems.

2. EVOLUTION OF URBAN THEORIES

It all started in the beginning of the 20th century, urbanism as a discipline has first seen the light. Its aim at that time was to provide a rational tool to help conceive and design cities. It was based on technical, economic and social grounds with an objective of settling disputable urban lands and conflicts. (El Malti, 2005) However, cities existed well before: historians stated that the first city to ever exist was Jericho, where remains of a temple that dated back to 9000 years BC were found.(Bairoch, 1985)

If the first theories around cities began with Plato's republic referring to city as a polis and democracy as the only way to progress revolving around the collective and public life, Le Corbusier, a few centuries later in his famous model of "The Radiant City" in Marseilles thought that technology was the essence of cities prosperity rather than democracy and moved away from the Greek ideals. Despite the misleading title of "Athens Charter", his theories were usually based rather on maximizing individual freedom than a life of community(Corbusier, 1957). A few years later, Ebenzer Howard synthesized the main currents of his time and advocated for cities that constituted the best aspiration of Man(Howard, 1965). In fact, his model reconciled politics, technology and a new component: ecology.(El Malti, 2005)

The critical trend at that time was a mechanist approach to urbanism: planners and architects entertained a utopia in their designs they wished to concretise it and many times were met by failure as was the case of the precedent models. And if there is one lesson we learnt from these models was that urbanism can't be reduced one or three components of the built environment, but is "a wider system of relations deriving from a few variables that determine the urban condition as they interact with each other."(Lutzoni, 2016)

This too was not a novel idea neither. In his Muqadima, Ibn Khaldun not only founded the new science of sociology but had as well insinuated the emergence of a science of cities (علم العمران).(Ibn Khaldun, 1377) And as earlier as that, the diversity of actors and processes was evident which makes cities complex phenomena par excellence(Bouayad, 2007). Meanwhile, in her seminal book "*L'urbanisme, utopie et réalités : une anthologie*" Françoise Choay attempted to trace the evolution of urban theory from the beginning of the 19th century until the World War 2, when according to the author urbanism as a science was first founded.(Choay, 1979) When other accounts refer to Ildfonso Cerda as the father of urban planning and sciences and in particular to his Barcelona plan.(Cerda, 1855)

It is important to note the absence of any consensus on when exactly this science emerged. To establish a harmonious chronology this paper will address: urban planning, urbanism, and urban design as subcategories of a whole and global science that is the science of cities. It is then natural to trace back the history and evolution of cities sciences to the apparition of the first city.

Lacking specific historical assumptions, in this paper, we will be addressing the common trends that were observed. Starting from antiquity to nowadays, we believe that city sciences went through historical periods that defined and shaped cities, as follows:

- The Age of Ideals (9000 B.C – 15th Century)

  During this period of history, cities were managed according to religious, cultural, or political ideas. One of the illustrious case studies is that of Plato in The Republic, where he advocates for his ideal city in 380 B.C, after him were different attempts of which we mention the prototype of Baghdad city plan which was designed to match a certain symbolism of *the imago-mundi*.(El Ghmari, 2017) However, this comes to an end with the emergence of Humanism in Europe and

Utopia by Thomas More where he presented an ideal city based on Renaissance ideas might be considered the last treatise on city sciences during this period(More, 1516).

- The Age of Wealth (16th Century – 17th Century)

At the beginning of this period major discoveries took place, among them was the New World. During this period, imperialism was at its height. In city sciences, planning was a means to facilitate commercial transactions. This trend was obvious especially in Italy(Roussel, 2018), where many cities were known to be ports for the flourishing commercial activity that was taking place across the Mediterranean sea, worthy of noting is the fact that this evolution has led to an increase in the numbers of population in Europe and their interest in urban centres. Meanwhile agricultural techniques saw a stark development by the end of this period. (Bairoch, 1985)

- The Age of Technology (18th Century –19th Century)

At the dawn of this age, there was a meaningful development of technologies applied to agriculture and the emergence of industrialization in Europe. This meant that cities had not only to accommodate residential and commercial needs but also include industrial quarters. Meaningful thought was spent on debating more hygienic cities or ideal models that could accompany the industrial revolution. Choay advances that there were two currents during this age: progressists and culturalists. The former was interested in enhancing human wellbeing to ensure maximum industrial yield. Functional models as Fourrier's "*Phalanstères*" in the early 19th century advocated for individual juxtaposed residential units to shape cities. The second current was based on a cultural nostalgia that considered cities as spaces for existential and spiritual fulfilment. The inspiration for this group came from history, archaeology, and poetry.(Choay, 1979)

Key culturalist figures were John Ruskin (Ruskin, 1849) whose ideas of applying morality to design has shaped cities and Camillo Sitte (Sitte, 1889) who thought of cities as creative spaces, and has emphasized the importance of its aesthetics.

- The Age of Information (20th Century - …)

Before the advent of CIT (Computation and Information Technology), the theoretical debate in the first half of the 20th century around cities was at the heart of sociology as industrialization impacted cities greatly (Sassen, 2010). Today's principal trends go back to three main currents on cities: the analytical debate (what is urban planning?), the urban form debate (what is a good urban plan?), and the procedural debate (what is a good planning process?).(Yiftachel, 1989) It goes without saying that these three main questions gave way to many interconnections and overlapping models for cities.(Aryal, 2008) But one defining idea during this age is the fact that cities are by essence social and should benefit all humans: "Cities have the capability of providing something for everybody, only because, and only when, they are created by everybody"(Jacobs, 1961).

By the invention of internet in the 1960's, there was a focus on the technological advances in cities. This led to many models and paradigms such as : smart cities, digital cities, creative cities and most recently learning cities and Fab cities. (Opromolla & Volpi, 2020)

The evolution of the science of cities as sketched swiftly in this short review, shows that cities are not only a product of one historical period but a culmination of each age's ideal and ideas. This rather complicates any attempt of understanding and studying cities. It is worth noting how city making shifted from being dictated from a single and central entity and serve specific interests (top-down) to becoming a work in progress where every resident has the right to benefit from cities (bottom-up).

Consequently, any attempt to study cities can't be based on a reductionist point of view of isolating each part as is the case with social science but should be considered in its entirety.(Miller & Page, 2007)

3. ARE URBAN SYSTEMS COMPLEX? (NOT SMART CITIES)

Earlier in the 60's, Jane Jacobs described cities as problems in organized complexity (Jacobs, 1961). On one hand complexity may be used to express our confusion and inability to simply explain and organize our ideas about phenomenon(Morin, 2005), in our case : cities. Before answering the question, it is primordial to define complex systems sciences and their main objects of study.

3.1 Complex systems sciences (CSS)

There is no clear date to when did complexity sciences first emerge, Mitchell attributes its premisses to Aristotle (Mitchell, 2009). However, in its current understanding it dates back and follows the evolution of four main intellectual traditions namely: dynamical systems theory , systems science, cybernetics, and artificial intelligence.(Castellani, 2018)

Complexity refers to phenomena that are BOAR: Between Order And Randomness and DEEP: since they cannot be easily Described, Evolved, Engineered, or Predicted. (Page, 2011) While complex systems are composed of numerous agents following simple rules without a central control that show an emergent self-organizing behaviours. (Mitchell, 2009) Emergence is a key trait of complex systems it's a structure or collective behaviour that arises from the interaction between the different entities of the system(Page, 2011). Complex systems display the following behaviours (Holland, 2014) :

- Self-organized,
- Chaotic and nonlinear changes that are sensitive to initial conditions,

- Fat-tailed occurrences (following Zipf's law), where rare event happen more than predicted by a normal distribution (bell-curve) or an exponential distribution.
- Adaptive interactions in time.

Complex systems studies have helped hone the interest in between the usual scientific boundaries (Miller & Page, 2007). Its objective is to provide a whole understanding of the world based on cross-disciplinary studies and looking for analogies across discipline that would help understand complex phenomena better.

In CSS it is held that systems are being constructed from the bottom up which challenges the traditional top-down conceptions to a "more organically structured" system.(Batty, 2013) In social systems, this can also be referred to as bifurcation theory, where not one optimal outcome is possible but a whole landscape of equilibria that can drastically change sometimes irreversibly. (Balmaceda & Fuentes, 2016)

The complexity of a phenomena doesn't increase as the number of agents and entities composing the system increases, it's rather due to the unpredictable and emergent interactions(Colding et al., 2018). It is true that a unified measure of complexity is still understudied (Balmaceda & Fuentes, 2016), but computation technologies and data mining are facilitating data aggregation and helping generate knowledge about complex systems. However, it's noteworthy that complex systems science isn't synonymous with computational science in fact one of the earliest models to have tackled a complex phenomenon – Schelling model of segregation only required a pen and a piece of paper. As it was noted earlier, a complex system is generally based on simple rules that generate volatile, uncertain, complex, and ambiguous outcomes (VUCA).

Complex systems are divided into two subsystems: complex physical systems (CPS) and complex adaptive system (CAS). The agents interacting in CPS typically follow fixed physical laws, only the positions of the agents change over time. Examples of CPS are fractals and networks. While CAS are characterized by agents that adapt to interactions and rules over-time.(Holland, 2014) These are autonomous entities that adapt their reaction to the outcomes – a sort of adaptation loop. This gives way to diverse yet individual components in the system.

Many disciplines are now benefiting from the application of complexity sciences which is presenting different ways of understanding natura, social, physical phenomena : economics (Mealy et al., 2019), disasters evacuation modelling (Carlson et al., 2014), opinions and belief systems (Galesic & Stein, 2018), biological networks (Girvan & Newman, 2002), political sciences and institutional design (Bednar, 2018), information theory and cognitive sciences(DeDeo, 2016) to cite a few applications.

3.2 Complex adaptive systems (CAS)

As for complex adaptive systems (CAS), they are found everywhere: starting from beehives to cancer cells and ending with cities. The entities composing CAS are changing over time and depend on the outcomes, in other words they adapt and respond to changes in their environment. The system doesn't adapt, but the agents alter their behaviours which leads to the system level adaptation. This is how emergence happens.(Page, 2011) Accordingly, agents adapt in three folds levels of activity: (1) actual performance (taking action), (2) credit assignment (rating available actions), and (3) rule discovery (generating possible actions).(Nel et al., 2018)

While in complex adaptive social systems are composed of interacting agents who are thoughtful, which makes it possible to understand the dynamics of strategic behaviour, chaos, anarchy and infinites of agents. Its central narrative is that viewing the social system as a complex evolving system—beyond control of government or anyone. It is more a living entity based on interactions and which outcomes are rather non-linear. Studying these systems is possible through computational models who are helping scientists explore these boundaries and emergence ideas to understand the robustness of CAS. (Miller & Page, 2007)

As we will see in the next section, cities are par excellence CAS and display most of their characteristics. However, this understanding emerged only in the last quarter of the 20th century (Batty, 2008) and is gaining momentum nowadays ever since it's clear that by the end of this century most of the world population will be living in cities with increasing complexity and interrelations.(Batty, 2013)

3.3 Complex adaptive urban systems (CAUS)

Despite the absence of a unifying theory as we have seen in the evolution of urban theory, there were more demands on immediate pragmatic solutions to planning problems. Understanding cities *per se* was also hindered by the insufficient computing power and data required for representing and explaining the complexity of cities(Baynes, 2009)

Although the idea that cities were described more accurately as featuring "organized complexity" was not a novelty (Jacobs, 1961), it's only 40 years later that a unifying framework emerged from complexity sciences to describe the science of cities and its main principles. (Samet, 2013)

Moreover, city planning overlaps with many different professions and disciplines which makes it even more complex to draw a clear boundary to its study and depends on the evolution of social problems. In other words, a city is an open system that is never in equilibrium.(Hudson et al., 1979) These are "emergent entities existing near a critical point of self-organization"(Baynes, 2009) "whose infrastructural, economic and social components are strongly interrelated". (Bettencourt & West, 2010)

As a matter of fact, cities are changing constantly while different movement of fluxes are taking place: human activities, networks, transport, …etc.(Batty, 2012a) These fluxes interact in various ways and give way to one key feature of complex systems that is non linearity: this means that unexpected transitions occur and the smallest perturbations have a wider effect on the system. Another important feature is that these are systems that are generated from the bottom up, made up of individuals or clusters who are interacting to some purpose and adapting to different perturbations in the system.(Batty, 2011)

In fact there are fifty other features arsing from the application of complexity sciences framework to cities science such as: co-evolution, path dependence, open systems, power law distribution, bifurcations, …etc as well as complexity tools namely: simulation models, scaling, game theory, …etc (Samet, 2013). These same processes are found at a global scale, which goes to the extent that cities might be considered as "scalar moments in a" global" trans-urban dynamic".(Sassen, 2010)

Consequently, thinking of cities shouldn't be considered a system that depends on a set of locations and geography which understanding is based on a "mix of architectural determinism and social administration", it should rather be based on sets of interactions and transactions between a multitude of individuals and agents following a bottom-up formation.(Batty, 2013)

Following the same logic, this also means that as much as cities are complex adaptive systems, smaller scale entities such as neighbourhoods, blocks, households are exactly similar in complexity and represent a nested level of description.(M. Allen et al., 2008)

Complexity sciences offers a set of tools to help understand CAUS, which are both helpful to predict or understand urban phenomena.

4. URBAN SUITE: A COMPLEXITY TOOLKIT

When it comes to studying cities using complexity sciences tools, these are generally described as social physics: usually these are analogies that are reflected in classical physics such as Newton's aw of motion that are central to modelling spatial interaction.(Batty, 2009) This section explores briefly a few applications of these quantitative tools which were made possible through the increasing availability of data on cities worldwide.(Luís M A Bettencourt, 2011)

4.1 Cellular automata (CA):

Cellular Automata described as "borderline biology" (Godfrey-Smith, 2003) "are *discrete*, *abstract computational systems* that have proved useful both as general models of complexity and as more specific representations of non-linear dynamics in a variety of scientific fields."(Berto & Tagliabue, 2017) One of the notable applications of this system in understanding cities, was a study conducted by Schelling on racial segregation in neighbourhoods in 1978. While agents take micro decisions, a macro pattern arises at the level of the city presenting highly segregated districts.(Schelling, 1978)

The cells or agents in CA follow the same simple rules while it is intuitive that they are doing the same thing, in reality complex and non-linear patterns emerge. (Wolfram, 2006) CA are thus simple models that can be applied to simulate urban dynamics and pattern formations in cities.(Balmaceda & Fuentes, 2016)

One recent study in Morocco has highlighted the importance of CA models in understanding the factors and drivers behind urban sprawl in small cities in developing countries.(Lahboub et al., 2018)

4.2 Agent based models (ABM):

In generative social science, it is held that "if you didn't grow it, you didn't explain its emergence". This is particularly why agent-based modelling as a bottom-up approach is an essential hybrid tool to study non-equilibrium systems. Consequently agent-based computational models as artificial societies are an interesting scientific instruments. (Epstein, 2006)

The advantage of agent-based modelling is that it counters the failure of reductionism to explain complex phenomena (Miller & Page, 2007). In fact, in one study agent-based models have helped improve the understanding of the Anasazi cultural change that has led to their disappearance.(Epstein, 2006) And apart from archaeology, agent-based models are also helpful in understanding urban phenomena such as: diffusion (information, pandemic, …) , flows (traffic, evacuation,…) or growth (urban sprawl, socio-economic dynamics,…)(Balmaceda & Fuentes, 2016)

4.3 Network theory:

A network can be defined as a set of entities connected to each other indifferent patterns. In network theory (also graph theory), there are different patterns of connections: small-world networks, scale-free networks, preferential attachment networks, …etc however only two are common an. These models are helpful in mapping out social networks for instance based on specific networks metrics: centrality, connectedness, eigenvalue... which provide techniques to analyse the structure of interacting agents in a complex system.(Jackson, 2019)

In a study conducted by (Banerjee et al., 2013), network theory has helped inform policy decisions related to the introduction of micro-finance in a village population and evaluate it. Whilst public policy is generally informed by classic economic studies, network theory is especially important to understand socio-economic disparities and inform broader policies.(Jackson, 2021)

In general, network theory is a representation method to define complex systems that are composed of entities that interact with each other. It's a way of articulating the complex system at different scales that can organiser in a hierarchy.(Batty, 2013) Apart from its social application, network theory has also shaped our understanding of transport networks, food webs in urbans environments, … etc(Balmaceda & Fuentes, 2016)

4.4 Scaling:

Scaling is a mathematical model that provides a way to deal with the diversity of scales and organisms in ecological systems. In simple terms, it's a benchmark against which species or populations can be compared. In fact, urban scaling theory's interest is to understand the dynamics and overall change in size or shape an urban system.(Batty, 2012b) Based on comparative studies between cities, there were major findings that shaped our understanding of the hidden laws that govern cities.(Luís Bettencourt, 2013)

For example in studying the relationship between patenting activity as a criteria of innovation and the population size, it was found that bigger cities grant more new patents disproportionately to smaller cities.(Luis M.A. Bettencourt et al., 2007) Another counterintuitive study argued that bigger cities do more with less resources, in an analogy to metabolic scaling theory.(Luís M A Bettencourt, 2011)

5. CONCLUSION

As it was demonstrated, the evolution of urban theory is now moving towards a unified theory that seeks a comprehensive understanding of cities and urban systems. While this is relatively new in city science field, this had always been at the centre of complexity sciences. The intersection with complexity sciences allows a fertile ground of research and collaborative speculations beyond "the usual academic boundaries" (Miller & Page, 2007)

Cities can be considered as complex adaptive urban systems that could be studied through the different models and tools offered by complexity sciences. In this paper only four tools and models were presented, although there are many analogies that have served to understand cities and urban dynamics such as game theory, or fractal theory.

This new emerging science might have direct implications on urban policy and planning, one of which is that urban systems can't be controlled and at best can be accompanied through an updated set of tools that encapsulate its complexity. (OECD, 2017) It will not only lead to a shift in urban policy but a revision of different frameworks that the metapolicy debate(Colander & Kupers, 2014) notably that of regulatory instruments.(Moroni, 2015) and even dare into uncharted grounds like informal settlements (Dovey, 2012).

Another consequence of introducing complexity sciences framework implies that planning education should shift towards a large set of skills beyond GIS awareness and include other statistical material for instance.(Batty, 2010) In short what complexity is teaching us is that there is more to cities, and that the only constant about urban systems is change where new patterns will always emerge in urban systems.

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8. REFERENCES

Aryal, S. (2008). *Evolution of Urban Design in Practice (Case studies of Chicago, Detroit and Cleveland through time)* [Master]. Virginia Commonwealth University.

Bairoch, P. (1985). *De Jéricho à Mexico : Villes et économie dans l'Histoire*. Gallimard.

Balmaceda, B., & Fuentes, M. (2016). Cities and methods from complexity science. *Journal of Systems Science and Complexity*, *29*(5), 1177-1186. https://doi.org/10.1007/s11424-016-6084-2

Banerjee, A., Chandrasekhar, A. G., Duflo, E., & Jackson, M. O. (2013). The Diffusion of Microfinance. *Science*, *341*(6144), 1236498-1236498. https://doi.org/10.1126/science.1236498

Batty, M. (2008). Fifty Years of Urban Modeling : Macro-Statics to Micro-Dynamics. In S. Albeverio (Éd.), *The dynamics of complex urban systems : An interdisciplinary approach*. Physica-Verlag.

Batty, M. (2009). Urban Modeling. *International Encyclopedia of Human Geography*, 51-58.

Batty, M. (2010). A changing picture of cities and their planning. *Environment and Planning B: Planning and Design*, *37*(5), 767-768. https://doi.org/10.1068/b3705ed

Batty, M. (2011). Cities, Prosperity, and the Importance of Being Large. *Environment and Planning B: Planning and Design*, *38*(3), 385-387. https://doi.org/10.1068/b3803ed

Batty, M. (2012a). Urban Regeneration as Self-Organisation. *Architectural Design*, *82*(1), 54-59. https://doi.org/10.1002/ad.1349

Batty, M. (2012b). Building a science of cities. *Cities*, *29*, S9-S16. https://doi.org/10.1016/j.cities.2011.11.008

Batty, M. (2013). *The New Science of Cities*. MIT Press.

Baynes, T. M. (2009). Complexity in Urban Development and Management. *Journal of Industrial Ecology*, *13*(2), 214-227. https://doi.org/10.1111/j.1530-9290.2009.00123.x

Bednar, J. (2018). Modeling the institutional matrix : Norms, culture, and robust design. In C. Ménard & M. Shirley, *A Research Agenda for New Institutional Economics* (p. 162-170). Edward Elgar Publishing. https://doi.org/10.4337/9781788112512.00028

Berto, F., & Tagliabue, J. (2017). Cellular Automata. In E. N. Zalta (Éd.), *The Stanford Encyclopedia of Philosophy* (Spring 2021). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2021/entries/cellular-automata/

Bettencourt, Luís. (2013). The hidden laws that govern city living. *New Scientist*, *220*(2947), 30-31. https://doi.org/10.1016/S0262-4079(13)62903-6

Bettencourt, Luís M A. (2011). *Bigger Cities Do More with Less*. 2.

Bettencourt, Luís M. A., & Gonzales, J. (2016). Science and Practice for Thriving Cities. *Innovations: Technology, Governance, Globalization*, *11*(1-2), 20-30. https://doi.org/10.1162/inov_a_00244

Bettencourt, Luis M.A., Lobo, J., & Strumsky, D. (2007). Invention in the city : Increasing returns to patenting as a scaling function of metropolitan size. *Research Policy*, *36*(1), 107-120. https://doi.org/10.1016/j.respol.2006.09.026

Bettencourt, Luis, & West, G. (2010). A unified theory of urban living. *Nature*, *467*(7318), 912-913. https://doi.org/10.1038/467912a

Bouayad, L. (2007). Architecture, histoire & patrimoine. *Architecture, Histoire et Patrimoine*. http://htapmp.blogspot.com/search/label/HTA%20S4%20F%C3%A8s%20-%202011

Carlson, J. M., Alderson, D. L., Stromberg, S. P., Bassett, D. S., Craparo, E. M., Guiterrez-Villarreal, F., & Otani, T. (2014). Measuring and Modeling Behavioral Decision Dynamics in Collective Evacuation. *PLoS ONE*, *9*(2), e87380. https://doi.org/10.1371/journal.pone.0087380

Castellani, B. (2018). *Map of the Complexity Sciences*. Art & Science Factory. https://www.art-sciencefactory.com/complexity-map_feb09.html

Cerda, I. (1855). *Teoría de la construccíon de las ciudades : Cerdá y Barcelona ; Teoría de la viabilidad urbana : Cerdá y Madrid* (1. ed edition). Ministerio para las Administraciones Públicas, Instituto Nacional de Administración Pública.

Choay, F. (1979). *L'urbanisme, utopies et réalités : Une anthologie* (Points essais edition). Seuil.

Colander, D., & Kupers, R. (2014). *Complexity and the Art of Public Policy : Solving Society's Problems from the Bottom Up* (Princeton University Press).

Colding, J., Colding, M., & Barthel, S. (2018). The smart city model : A new panacea for urban sustainability or unmanageable complexity? *Environment and Planning B: Urban Analytics and City Science*, 239980831876316. https://doi.org/10.1177/2399808318763164

Corbusier, L. (1957). *La Charte d'Athènes*. LES EDITIONS DE MINUIT.

DeDeo, S. (2016). *Information Theory for Intelligent People*. 15.

Dovey, K. (2012). Informal urbanism and complex adaptive assemblage. *International Development Planning Review*, *34*(4), 349-368. https://doi.org/10.3828/idpr.2012.23

El Ghmari, S. (2017). *La force du symbole en architecture* [Travail Personnel de Fin d'Etude - Master]. Ecole Nationale d'Architecture.

El Malti, M. (2005). *L'urbanisme et la question de la ville*.

Epstein, J. M. (2006). *GenerativeSocial Science : STUDIES IN AGENT-BASEDCOMPUTATIONAL MODELING* (Princeton University Press).

Galesic, M., & Stein, D. L. (2018). Statistical Physics Models of Belief Dynamics : Theory and Empirical Tests. *ArXiv:1706.02287 [Physics]*. http://arxiv.org/abs/1706.02287

Girvan, M., & Newman, M. E. J. (2002). Community structure in social and biological networks. *Proceedings of the National Academy of Sciences*, *99*(12), 7821-7826. https://doi.org/10.1073/pnas.122653799

Godfrey-Smith, P. (2003). *Theory and Reality : An Introduction to the Philosophy of Science* (The University of Chicago Press). https://press.uchicago.edu/ucp/books/book/chicago/T/bo3622037.html

Holland, J. H. (2014). *Complexity : A Very Short Introduction* (Oxford University Press).

Howard, E. (1965). *Garden Cities of To-Morrow* (F. J. Osborn, Éd.; 1st edition). The MIT Press.

Hudson, B. M., Galloway, T. D., & Kaufman, J. L. (1979). Comparison of Current Planning Theories : Counterparts and Contradictions. *Journal of the American Planning Association*, *45*(4), 387-398. https://doi.org/10.1080/01944367908976980

Ibn Khaldun, A. (1377). *مقدمة ابن خلدون* (خ. شحادة, Éd.).

Jackson, M. O. (2019). *The Human Network : How Your Social Position Determines Your Power, Beliefs, and Behaviors* (Illustrated edition). Pantheon.

Jackson, M. O. (2021). *Inequality's Economic and Social Roots : The Role of Social Networks and Homophily*. 41.

Jacobs, J. (1961). *The Death and Life of Great American Cities*. Random House.

Lahboub, Y., Bachaoui, E. M., El Harti, A., & El Ghmari, A. (2018). Multi-level Cellular Automata-based housing allocation model for small cities in developing countries : A case study of Kasba-Tadla city, in Morocco. *International Journal of Urban Sustainable Development*, *10*(2), 186-202. https://doi.org/10.1080/19463138.2018.1461628

Lutzoni, L. (2016). *In-formalised urban space design :Rethinking the relationship between formal and informal*. https://cityterritoryarchitecture.springeropen.com/track/pdf/10.1186/s40410-016-0046-9

M. Allen, P., Strathen, M., & Baldwin, J. (2008). Complexity : The Integrating Framework for Models of Urban and Regional Systems. In S. Albeverio (Éd.), *The dynamics of complex urban systems : An interdisciplinary approach*. Physica-Verlag.

Mealy, P., Farmer, J. D., & Teytelboym, A. (2019). Interpreting economic complexity. *Science Advances*, *5*(1), eaau1705. https://doi.org/10.1126/sciadv.aau1705

Miller, J. H., & Page, S. E. (2007). *Complex adaptive systems : An introduction to computational models of social life*. Princeton University Press.

Mitchell, M. (2009). *Complexity : A Guided Tour* (Oxford University Press).

More, T. (1516). *L'utopie* (Folio). Gallimard.

Morin, E. (2005). *Introduction à la pensée complexe*. Édition du Seuil.

Moroni, S. (2015). Complexity and the inherent limits of explanation and prediction : Urban codes for self-organising cities. *Planning Theory*, *14*(3), 248-267. https://doi.org/10.1177/1473095214521104

Myers, D., & Kitsuse, A. (2000). Constructing the Future in Planning : A Survey of Theories and Tools. *Journal of Planning Education and Research*, *19*(3), 221-231. https://doi.org/10.1177/0739456X0001900301

Nel, D., du Plessis, C., & Landman, K. (2018). Planning for dynamic cities : Introducing a framework to understand urban change from a complex adaptive systems approach. *International Planning Studies*, *23*(3), 250-263. https://doi.org/10.1080/13563475.2018.1439370

OECD. (2017). *Debate the Issues : Complexity and Policy making* (P. Love & J. Stockdale-Otárola, Éds.). OECD. https://doi.org/10.1787/9789264271531-en

Opromolla, A., & Volpi, V. (2020). Cities as Complex Systems : Some Characteristics of the Hybrid Urban Spaces. *International Journal of Urban Planning and Smart Cities*, *1*(2), 1-16. https://doi.org/10.4018/IJUPSC.2020070101

Page, S. E. (2011). *Diversity and Complexity* (Princeton University Press).

Roussel. (2018). Pollution atmosphérique. Introduction : « De Jéricho à Mexico. Villes et économie dans l'histoire ». *Pollution atmosphérique*, *237-238*. http://lodel.irevues.inist.fr/pollutionatmospherique/index.php?id=6755

Ruskin, J. (1849). *The Seven Lamps of Architecture* (Reprint edition). Dover Publications.

Samet, R. H. (2013). Complexity, the science of cities and long-range futures. *Futures*, *47*, 49-58. https://doi.org/10.1016/j.futures.2013.01.006

Sassen, S. (2010). The city : Its return as a lens for social theory. *City, Culture and Society*, *1*(1), 3-11. https://doi.org/10.1016/j.ccs.2010.04.003

Schelling, T. C. (1978). *Micromotives and Macrobehavior*. Norton.

Sitte, C. (1889). *The Art of Building Cities : City Building According to Its Artistic Fundamentals* (C. T. Stewart, Trad.; Illustrated edition). Martino Fine Books.

Wolfram, S. (2006). How do simple programs behave. *Architectural Design*, *76*(4), 34-37. https://doi.org/10.1002/ad.291

Yiftachel, O. (1989). Towards a New Typology of Urban Planning Theories. *Environment and Planning B: Planning and Design*, *16*(1), 23-39. https://doi.org/10.1068/b160023

9. ADDITIONAL READING

- Goldin, I., & Mariathasan, M. (2014). The Butterfly Defect: How Globalization Creates Systemic Risks, and What to Do about It (Princeton University Press).
- Newman, M. (2010). Networks: An Introduction (1st edition). Oxford University Press.
- Page, S. E. (2018). The Model Thinker: What You Need to Know to Make Data Work for You (1st edition). Basic Books.
- West, G. (2018). Scale: The Universal Laws of Life, Growth, and Death in Organisms, Cities, and Companies (Reprint edition). Penguin Books.

10. KEY TERMS AND DEFINITIONS

Complexity Sciences: also, Complex Systems Science (CSS) is a science that studies complex systems that are a BOAR (between order and randomness, Scott E; Page) and can be described as VUCA (volatile, uncertain, complex, and ambiguous) in different sciences and tries to find analogies across these disciplines to be able to understand complex phenomena requiring new methodologies and scientific frameworks.

Emergence: an inherent characteristic to complex systems that describes the unexpected outcomes of a complex system interaction and evolution. In other words, thorough knowledge of the system's components can't explain nor predict the general and macroscopic behaviour: the whole is more than the sum of the parts.

Normal distribution: in probability it is also called a bell curve. It describes a continuous probability distribution for a random variable, symmetrical on both sides of the mean.

Small world network: also refers to Watts-Strogatz toy network. It is a network that describes a short path between any two components of the same network. It's a network that has short paths between most pairs of components and a few long-distance paths across the network.

Complex adaptive systems (CAS): a variation of complex systems where components/agents have the capacity for adaptation, and where bottom-up self-organization and top-down integration creating a dynamic of complexity. Examples of CAS: beehives, aunts colonies, human immune system, …

Non-linearity: in statistics it refers to an absence of correlation between an independent variable and dependent variable. In CSS, it is one of the example of emergence that has a disproportionate cause and effect dynamic.