Cities as they could be: Artificial Life and Urban Systems

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Abstract

Introduction

The understanding of processes driving the growth of cities, or more generally the evolution of urban systems, and approaches for a sustainable design and management of these, have for more than 100 years been tightly linked to concepts borrowed from biology such as evolution (Batty and Marshall, 2009). Inventing novel ways to design cities, beyond predicting their evolution (Batty, 2018), is a major asset to tackle climate change and sustainability issues (IEPSFC, 2018). In that context, Artificial Life (ALife) approaches to urban systems have several advantages, including knowledge transfer from biology and ecology where relevant concepts such as resilience or morphogenesis are thoroughly studied, a strong practice of interdisciplinarity, or methodologies and tools such as agent-based modeling and cellular automata, among others. Following the seminal view of "Life as it could be" by Langton (1986), an explicit ALife take on urban issues would consist in studying "Cities as they could be". Although not explicitly listed in application domains of ALife by Kim and Cho (2006), is is included through the use of methods and in relation with economic models. Two of archetypal "would-be" worlds of Casti (1997) are related to urban systems (transportation and resource exploitation). Siqueiros-Garca (2019) recently introduced a conceptual frame considering cities from an organismic perspective, while Sayama (2019) showed that open-endedness has a strong potential to develop sustainable social systems.

Diverse streams of research on urban systems have already linked with ALife. From a methodological viewpoint, the use of cellular automata and agent-based models for urban growth and urban dynamics has a long history Torrens (2003). These can be used for example to generate building layouts and road networks of synthetic cities (Kato et al., 1998) or at the scale of districts (Raimbault and Perret, 2019). Integrating such models into evolutionary computation algorithms widens the scope of possible synthetic cities (Kato et al., 2000). Other dimensions such as land prices and residential dynamics can be grasped using agent-based models (Takizawa et al., 2000). Generative processes can also be used for interactive urban design (Openshaw, 1995). The study of urban morphology may be done with methods used to study morphogenesis, and Medda et al. (2009) apply reaction-diffusion equation to model the relation between transportation and land-use, while Raimbault (2018) shows that the combination of aggregation and diffusion produces realistic urban forms. DAcci (2013) explores possible future sustainable urban morphologies. Lucic and Teodorovic (2002) use bio-inspired algorithms to solve difficult transportation planning problems. The concept of urban metabolism introduced by Olsen (1982) also comes as a transfer from biology.

Moreover, the field of Artificial Intelligence (AI) has also numerous application related to urban systems. Wu and Silva (2010) review AI application to the prediction of land-use dynamics, unveiling a very broad range of methods ranging from evolutionary computation to neural networks, and suggesting that integrative and interdisciplinary approaches still lack for more robust urban applications. White (1989) show for example that a neural network trained appropriately can learn to plan transportation infrastructures. Zheng et al. (2014) define the emerging field of Urban Computing as the convergence of ubiquitous urban data with artificial intelligence and new urban services, with varied domains of application including transportation, economy, environment, and planning. AI can for example be applied in real-time conditions to manage highway traffic (Ma et al., 2009). Other urban dimensions which require accurate predictions with a high spatio-temporal resolution, such as water demand (Adamowski and Karapataki, 2010) or electric vehicles grid management (Rigas et al., 2014), are other examples where AI is successfully applied.

Thus, as both ALife and AI have been broadly applied to urban systems, we can first ask what are their respective extent in terms of methodologies, tools, concepts, and application domains, and secondly what are their remaining potentialities to enhance the understanding and management of cities, in other words what research directions and concepts in that particular context remain to be explored. This paper proposes to tackle these two questions by means of a systematic literature mapping method based on citation networks. More precisely, our contribution (i) constructs and explores a large citation network of around 250,000 papers, to map the respective contributions of ALife and AI to the urban literature, and their relations; and (ii) explores more thoroughly crucial concepts still loosely applied or understood in an urban system perspective.

The rest of this paper is organized as follows: we develop in the next section the bibliometric analysis based on citation networks to map the scope of artificial life and artificial intelligence approaches to urban systems. Building on this systematic mapping, we then review the principal points in which artificial life can significantly inform the study of urban systems. We finally discuss research directions opened by taking such a viewpoint of "Cities as They Could Be".

Bibliometric analysis

Method

Literature mapping and quantitative bibliometrics have been widely used to reinforce knowledge in most disciplines, and are part of a field of study in itself Leydesdorff (2001). They are furthermore important to enhance reflexivity which is crucial in disciplines studying socio-technical systems Raimbault et al. (2019). In the case of artificial intelligence, several mappings have been proposed, for example from a semantic (Van Raan and Tijssen, 1993), spatialized (Niu et al., 2016), or journal-level (Ibáñez et al., 2011) viewpoint. Squazzoni and Casnici (2013) analyze the impact of the Journal on Artificial Societies and Social Simulation. Aguilar et al. (2014) show the evolution of theme frequency in time for the Artificial Life journal. There is however to the best of our knowledge no previous attempt of such an exercise for Artificial Life at a large scale. We propose here such a literature mapping approach to both ALife and AI, in the specific context of urban systems applications.

We use therefore a citation network analysis, applying the methods and tools developed by Raimbault (2019). In a nutshell, citation networks are constructed by first constituting a seed corpus using a keyword search, and then by collecting papers citing papers in this corpus, recursively to a certain level.

The keyword we use to constitute our seed corpus follows , and we thus consider only the requests `Artificial Intelligence AND Urban` for AI approaches and `Artificial Life AND Urban` for ALife. Using alternative terms such as "machine learning" or "city" expands the scope too much and yield non relevant results. We construct initial seed corpuses using these requests Some references which obviously did not fit the scope were manually removed.

Results

Cities as they could be: strengthening ALife concepts in urban science

We turn now to a more thorough development of some concepts related to ALife which should have either a high theoretical importance for the study of urban systems, or a high potentiality to introduce novel approaches. This list stems from the conjunction of open issues in urban science (Lobo et al., 2020) with conclusions from the previous literature mapping on underexplored paths. It can be understood as main arguments of why ALife concepts may help understanding, planning, designing and managing in a better and more sustainable way.

Tools and methods

Biomimetism

Taylor Buck (2017)

Urban ecology

Morphogenesis and autopoiesis

Urban evolutionary theories

The definition of an "Urban DNA", i.e. an extension of the gene concept in evolution or of the *meme* concept in cultural evolution, or even an approach combining different types of replicators Bull et al. (2000), remains an open question.

Innovation in urban systems

Linking Urban ALife and AI: urban computing

Discussion

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