Pedagogy for the City as an Emergent Cognitive System for Sustainability

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Abstract

In this short paper, we develop the case for moving away from the concept of a smart city in which the focus tends to be on shifting managerial responsibility onto computers. We offer the alternative conception of the city as an ecosystem, a complex adaptive system, and draw upon the biology of cognition to construe cognition as the skilful adaptation to living sustainably. Such skilful adaptations necessitate human operators and managers themselves to both develop necessary systemic redundancy to withstand future shocks, but also to acquire skills in multi-faceted domains and disciplines, including the use of Artificial Intelligence, to simulate future scenarios and to plan accordingly. To attain such skills and competencies, we briefly outline a viable and relevant transdisciplinary pedagogy for future city managers to develop smart sustainable cities.

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Work on urban systems from the 1960's onwards has argued that the city is a complex adaptive system that is multi-scalar, interconnected and emergent from the bottom up (e.g. Batty & Xie, 1994; Portugali, 2000). More recently the concept of the Smart City (Caragliu et al., 2011) has built upon this interpretation of cities as complex, and thereby unpredictable, but, in practice, has often tended to adopt a technical, digital focus for addressing this complexity – potentially treating the city as complicated (comprised of components) rather than complex (emergent and irreversible) (Cugurullo & Ponzini, 2018).

By adopting this paradigm of the city as complex (e.g. Cosgrave, 2018) and cautioning about an over-reliance on digital solutions, this paper will highlight three central and interlinked questions – firstly, what generic skills are required to underpin a holistic understanding of the city that can complement the core disciplinary and practice-based specialisms and how can we teach these? Secondly, while it is important to learn from the past and from other case-based context specific examples these will not be replicated, therefore, how can we best generate future scenarios and learn from them? This highlights a need to *avoid* unsustainable futures in addition to pursuing sustainable ones such as those proposed as the 11th UN Sustainable Development Goal (SDG) on sustainable cities and communities. Finally, how can different modelling approaches align with these cross-cutting skills to generate futures in an iterative manner, i.e. learning from stakeholder knowledge and inputting this as the basis for making informed judgements about which potentially unsustainable pathways need to be guarded against?

The paper will address these questions through the following structure; we will briefly look at how the narrative of cities has changed while retaining an underlying recognition of complexity. The range of skills for understanding urban systems will then be considered, with a focus on cross-cutting or transdisciplinary skills, and the pedagogic implications of this will be introduced. The paper will conclude by outlining how different modelling approaches can align with these transdisciplinary skills and generate scenarios that can inform decision making and particularly decisions related to the redundancy required to avoid unsustainable futures.

CITIES AS COMPLEX SYSTEMS – MOVING FROM SMART TO COGNITIVE CITIES

As inward migration to urban centres continues to escalate, it becomes increasingly imperative for population health and wellbeing for such conurbations to invest in ensuring that they are future proofed, that they avoid unsustainable futures, and that they can adapt responsively to emergent and novel threats and risks, be these due to climate change, pandemics, or anthropogenic ruptures, such as economic recessions (e.g. Lim & Kain, 2016). In this paper we reimagine the city as a complex system, a system which has more in common with an ecosystem as a complex mixture of organic and inorganic matters, supported by metabolic stocks and flows which feed its multi-faceted operations.

Imagining a city as an ecosystem is to treat it as a whole complex system within which humans realise themselves in a reciprocal co-adaptation with their environments (e.g. Plummer & Armitage, 2007). Some of the characteristics of a complex system are that the system is itself adaptive – it is dynamic, and changes over time, and rarely in a linear trajectory. Such changes at both large and small scales of size and speed lead to multiple interactions among its components, and this history of local interactions give rise to emergent phenomena, many of which cannot be anticipated.

From such a perspective, we argue that it is not enough for cities to be 'smart', which is all too often a synonym for shifting managerial responsibility from human control to information and communications technology (Cavalcante et al., 2016). By drawing on the paradigm of the biology of cognition, we propose that rather than being smart, we require cities to be 'cognitive'. Cognition is understood as the experiential encoding of knowledge and behaviour resulting from the history of adequate action relative to the domain within which it realises itself in the conservation of its autonomy (or identity as a cohesive unity) through an ongoing dynamic of structural coupling -- the reciprocal interaction of people and places (Maturana & Varela, 1992).

By extending this paradigm to the human-urban ecosystem, a city is considered to be cognitive to the extent that it successfully conserves its coherence and identity despite changes within the context within it is realised as such. By repositioning cities as cognitive, we move away from the traditional input-output model of information processing and towards a model of a dynamic and adaptive unity, which is able to adapt to changes in its context as a series of compensatory adaptations to maintain its homeostasis and its organisational coherence.

The implications of this shift from a 'smart' to a 'cognitive' city, as proposed here, means that the cognitive city draws on its capacity for resilience, its requisite variety (Ashby, 1957), to absorb shocks and pressures without changing state. Resilience means, therefore, building in redundancy (i.e. spare capacity) which provides a system with sufficient variety to draw upon in successive adaptations to compensate for shock, including those of falling short on our own aspirations.

For example, if floods or droughts render the rural hinterland untenable for agriculture, what redundancies can a cognitive urban system draw upon to ensure its populace survive? This would mean investing in urban-based horticulture, such as using rooftops and spare land to grow food on, to use vertical farms, and so on. If a city were to become flooded due to rising tides, could it build in redundant transport networks, spaces for evacuations located at different sites, decentred first responder stations, spare beds in hospitals, and so on? In other words, how well is a city prepared to quickly and relatively seamlessly respond to, and absorb, shocks both sudden or prolonged? While an engineering account of resilience might advocate a model that accounts for deviation around a consistent norm, a social-ecological account poses the more troubling position about the amount of stress a system can take before its state conditions cross a threshold and the system orients around alternate stable, although potentially undesirable, state conditions (Brand & Jax, 2007; Walker et al., 2006). To enhance the city's social-ecological resilience in such ways is, in the terms used here, to help transition it towards becoming a cognitive city.

ATTRIBUTES FOR A PEDAGOGY OF SMART CITIES

In order to understand what generic skills are required to underpin a holistic understanding of the city that can complement practice-based specialisms, it is helpful to explore how smart city research is represented in the research literature. While it is generally accepted that there is no single definition of a 'smart city' (Caragliu et al., 2011; Albino et al., 2015), two main streams of research can be identified. For example, Michelucci et al. (2016) and David and McNutt (2019) describe the first as a more technology centred approach, focused on ICT application domains, and the second as a more people centred approach in which technology and infrastructure are viewed as enabling factors to achieve welfare, social inclusion and human capital, illustrating a form of structural coupling in which the two elements are mutually influential.

These research streams are also reflected in the British Standard (BSI, 2014, p. 12), where 'smart' is defined as "the application of autonomous or semi-autonomous technology systems to achieve greater utilization of resources, limiting or reducing per capita resource consumption to maintain or improve quality of life," and the 'smart city' as the "effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens."

As a result, the smart city is often discussed in terms of hard and soft domains. This approach can be helpful to identify skills and knowledge needs for the different stakeholders. For example, Michelucci et al. (2016) identified competencies for smart city managers based on the detailed taxonomy of domains developed by Neirotti (2014). Their proposed framework highlights that managing smart cities and developing, adapting and integrating smart urban systems requires an understanding of a range of soft and hard domains, and that in addition to the need for such specific expertise, it is crucial that stakeholders are aware of links to other expertise and the wider urban system (Michelucci et al., 2016). "If the engineering sector is to effectively engage with socio-economic concerns of the smart city that meet the needs of both citizens and policy makers whilst maintaining technical rigor, it is incumbent on both communities of experts to relate to one another's modes of thinking, rather than sitting at a dismissive distance" (Cosgrave, 2017, p. 92).

In terms of sustainable cities, MacDonald et al. (2020) present key individual sustainability competencies of managers in public sector. The most known competencies are communication, change management, anticipatory thinking, systems thinking, collaboration, and interpersonal competence. Knowledge of sustainability principles and valuing environment, social inclusion and diversity are also noted as sustainability competencies which could facilitate a journey towards sustainable smart city. Lambrechts et al. (2019) explored the role of individual sustainability competences in eco-design building projects of small- and medium sized enterprises (SMEs) in the Netherlands, as built environment forms part of smart sustainable cities and plays a role in different phases and characteristic aspects of building projects, such as initial inspiration for eco-design; project development and stakeholders' involvement. The most apparent sustainability competencies identified were related to strategic management and action, diversity, interdisciplinarity, and interpersonal aspects. However, systems thinking, and foresighted thinking competencies occurred considerably less apparent in this context.

Neirotti (2014) identifies a taxonomy of smart city domains relating to the functioning of the city, which includes natural resources, waste, water and energy, transport and mobility, buildings and infrastructure, and the local economy and employment. Each of these domains draw upon a set of core competencies, for example management and governance, data, community and technology skills (with a focus on planning and management of systems/ technology) (Michelucci et al., 2016; David & McNutt, 2019). Meijer and Bolívar (2015) argue that smart city governance is about crafting new forms of human collaboration using ICTs to achieve better outcomes and more open governance processes. Therefore, sustainability competencies can play a crucial role in governance and management of these smart city interventions as city managers need to be educated in a number of ways to govern a city sustainably and future proof (Brundiers et al., 2021). The (co)development of smart city innovation requires managerial and governance skills (human component) for the successful exploitation of the innovation opportunities offered by technologies. Previous studies highlight the role of entrepreneurship and governance in smart cities for a broader perspective that introduces the entrepreneurial, governance and management's skills as enabling factors of innovation for overcoming the technology-based view that considers smart technology as the innovative driver for smartness in cities and communities (Ciasullo et al., 2020).

Similarly, the EU report on 'Skills for smart industrialisation and digital transformation' highlights a need for transferable and interdisciplinary skills, and identifies that current education initiatives often focus on technical aspects, some in combination with managerial and entrepreneurial skills, whilst systems thinking and emotional intelligence are often absent (EC, 2019). The report references that T-shaped models can show how general leadership and interpersonal skills, together with general problem-solving and critical thinking skills, provide an overarching link that ensures that the deep technical knowledge and subject expertise that exists in each domain can be utilised effectively across disciplines and between stakeholder groups (citizens, policy makers, practitioners / managers and academics – see Figure 1).

This acknowledges that whilst the cross-cutting skills are vital for understanding the smart city and working and living effectively within it, they should not come at the cost of deep subject expertise, but must be an integrated component of skill development, and hence of teaching and learning in all subject areas and at all levels and stages of education from early years to the older members of the community.

However, this is not trivial, as the conceptualization of the smart city as a complex socio-technical problem does not align well with the engineering practice, which is based on reductionist thinking and clear design specifications (Cosgrave, 2017). Indeed, conceptualising the city as a 'cognitive' unity requires a multi-disciplinary team of practitioners and stakeholders who are able to abstract critical influences of the environment within which the city persists and retains its coherence and to articulate these as input factors for incorporating into the development of any modelling or simulation exercises, as well as to interpret and apply any outputs to the realisation of these as policy recommendations.

PEDAGOGICAL APPLICATIONS

It is unrealistic to shift responsibility for city management onto computer technologies alone. Indeed, humans will always remain necessary to responsive and adaptive management. However, to do so effectively necessitates that human operators and managers are suitably equipped with the skill sets to manage within complex adaptive systems. In part, this means the capacity to draw on current academic and scientific research, and to be able to develop strategies for applying these to real-world contexts in a radical 'democratisation' of transdisciplinary knowledge production, in what is often referred to as 'mode-2' science (Gibbons et al., 1994; Nowotny et al., 2001). Moreover, doing so necessitates that operators and managers are equipped to learn how to learn, and to apply learning acquired previously to novel contexts (Mitchell & Lemon, 2020).

A few examples of candidate transferable and transdisciplinary skills include the analysis of social and other network relations, to map these out and to identify 'bottlenecks' and short hops for the flow of information and resources, to isolate small world phenomena, and bridges which act as hubs connecting one region of a network to another, along with recognising indicators of network vulnerability and risk. In addition, modelling skills such as running simulations using agent-based software to explore emergent phenomena from different starting conditions are critical to develop a 'library' of future scenarios to evaluate which demonstrate greater relative impacts and probabilities of occurring. These can then be drawn upon to strategise the investment of resources and generating redundancies, in an iterative process of abductive reasoning (Flyvbjerg, 2001).

Any attempt at the cognitive mapping of pedagogical requirements in the context of smart cities will have to include an iterative process within which Artificial Intelligence (AI) research and pedagogy inform each other. There is a need for a continuous discussion over the potential role of AI in generating scenarios (e.g. Abdelhak et al., 2012; Bertelle et al., 2010), from real-world applications for pedagogical training and appreciating the practical applications of AI in developing smart cities (Ayesh, 2014).

Strategies to respond adaptively to emergent risks can be modelled iteratively, through linking mental models about how the world is thought to work, to cognitively map these to scenarios simulated using Agent-Based Modelling (ABM), which allow for multiple scenarios to be tested in a safe, reversible space. Using 'scenario-based strategic planning', Schwenker and Wulf (2013) propose a method for developing and analysing possible future states and development paths, not to predict the future, but rather to better understand the logic of the developmental trajectories and the probable scenarios that emerge as outcomes. The contribution of ABM to such scenario modelling and simulation is not only that it reduces the cognitive overload on human strategists to imagine multiple scenarios, but also that computer simulation can run a range of simulations rapidly and without bias favouring one or other outcome, and can do so repeatedly when one or more starting conditions are amended or updated in the light of new information becoming available.

Cognitive agents based simulators (Abdelhak et al., 2012) can provide frameworks for realistic modelling of cities including modelling of human participation in the spatial environment of the city. These simulators would enable the development and running of scenarios with high vitality and dynamism reflecting the complexity of the city as a system and provide easy to use tools to extend this modeling to the new generations of smart city as a cognitive system.

Still, it is important to highlight how AI is perceived and how attempts to use technology as an easy solution may miss out on identifying the right questions to answer about future living and cities. Doing so makes it ever more important for relevant pedagogical requirements to be identified, mapped and addressed as part of training future engineers, technologists and other stakeholders in the cognitive city. So, what kind of topics are to be taught and what kind of skills are to be developed? Some initial guidelines could be that: (1) to have clear understanding of AI and what can be done; (2) to separate technology from applications, which is important in regulating Applied AI; (3) and to build on (1) for estimating the consequences of the practical applications of AI or the strategic plans recommended by ABM.

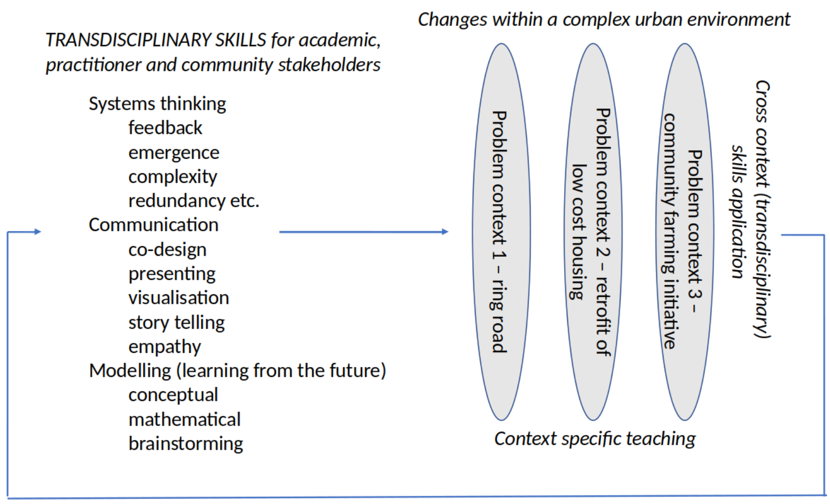
Figure 1 provides a provisional insight into what these cross-cutting, transdisciplinary skills, might look like. They are currently being considered by the authors for post - graduate training into Smart City management. Such skills are intended to complement the technical and domain expertise mentioned above (e.g. transportation, education, health care etc.); they should also be made available to community stakeholders and others engaged in designing, adapting and 'living' the urban narrative.

The figure suggests that core transdisciplinary capabilities include: 1. the ability to think systemically, i.e. to develop an holistic appreciation of how the city functions and evolves and specifically how interventions in one sectoral or geographical area might impact on those elsewhere (e.g. in Figure 1 – the ring road may affect land prices for low cost housing and energy bills may encourage people to engage in local food production); 2. the need for empathy -awareness of who the stakeholders are, what perspectives they might adopt and how to communicate with those different audiences and 3. the ability to learn from the future. At a transdisciplinary level, this will involve various forms of qualitative future casting such as brainstorming, Delphi approaches, community engagement etc. While this aspect of exploring and projecting the city's future should involve all actors it is here that the potential of computer simulation is key to learning. While the models should reflect the available data relating to the city and the qualitative inputs from stakeholder engagement they should also generate futures that may not, hitherto, have been anticipated. As such, there is a feedback loop between the generated scenarios and the learning about those potential outcomes from different interventions (e.g. the building of a ring road or a new peri-urban development). That learning will also form the basis for judgements about what resources might support some form of adaptive response

- e.g. through the generation of appropriate redundancy - or what can be rejected. Computer generated futures can help us identify what might be unsustainable and as such provide a vision of the future that is responsive and adaptive rather than prescriptive and in pursuit of an elusive sustainability (Lambrechts, 2020; Mitchell et al., 2020).

What is central to the approach suggested in Figure 1 is the need for these skills to be assimilated by all actors in the smart city narrative. This will mean the alignment of the skills with the current capabilities of the actors – for example the core principles of systemic thinking should be taught to everyone from a young age. The 'technical sophistication' of that thinking may alter with specialist knowledge but this in turn will highlight three additional, and important points. Firstly, that expertise has to be made comprehensible for other stakeholders (e.g. community actors and policy makers) to contribute to a more inclusive systemic analysis. Secondly, smart city management has to have the capability to cross the sectoral and policy boundaries that are directly and indirectly influenced by an initiative elsewhere – when, for example, land prices influenced by a new ring road make low cost housing more, or less, achievable in that location. Thirdly, we have highlighted the potential futility of chasing, linear, sustainable futures rather than identifying, and avoiding, what might be unsustainable ones; linked to this is the need to take a similar, sceptical, attitude to the premature search for consensus. By exploring the perspectives of multiple actors we can start to envisage a 'complex' and diverse landscape which suggests that the initial consensus around an issue should be one that is accepting of, and emerges out of, difference (Lemon et al., 2014).

Figure 1. A schematic of cross-cutting skills



Source: the authors.

We are now at the point where we can summarise our response to the three questions motivating this paper. In terms of generic skills, we have identified the skills associated with transdisciplinary thinking, such as thinking systemically, engaging empathy and anticipating future scenarios and learning from those. Secondly, we identified how we can generate a range of future scenarios, drawing on the work in scenario-based strategic planning, and third, we can privilege the learning and experience of key stakeholders to inform modelling inputs, using ABM and other simulations to test these against known challenges and to indicate potential unintended outcomes.

CONCLUSION

This paper has briefly developed the argument in favour of shifting away from conceptualising the city as smart, where doing so involves little more than shifting managerial responsibility to ICT. Instead, we have proposed that we re-conceptualise the city as an ecosystem and, as such, a complex adaptive system. Drawing on the biology of cognition, we have also argued that we rethink cognition not so much as information processing, but rather as the on-going real-time activity of solving the problems of living, which means adaptation, to conserve the cognate system's coherence despite successive pressures and shocks occurring in the context within which it persists.

The implications of this shift in conceiving of the 'cognitive city' are manifold, but here we have addressed only two. The first is the necessity to acquire systemic redundancy to foster and facilitate the city system's social-ecological resilience to environmental perturbation, be these anthropogenic or natural. The second is to recognise that a cognitive city requires human managers to be equally as adaptive and resilient, and we have put forward the case that doing so requires a pedagogy of transdisciplinary skills. Such skill sets include not only the social sciences with respect to human engagement, empathy, planning, project management, and systems thinking in the round; such skill sets must also include the ability to utilise AI and agent-based modelling to simulate future developmental trajectories as a means with which to anticipate the future and to plan accordingly.

We recognise that in the space available, we can but scratch the surface of what will likely become a topic of increasing interest and importance to academics and practitioners alike, and our intent is to develop these ideas in more depth in subsequent work. Such work may begin to explore the potential linkages between the skills required for planning social-ecologically resilient and cognitive cities and how those might feed forward to supplement and inform the skills necessary to facilitate progress against SDG 11 (e.g. Brundiers et al., 2021; MacDonald et al., 2020). It may also involve a critical interrogation of the values that inform and motivate our understanding of what ‘progress’ and ‘development’ refer to given the threat of climate change, the Anthropocene, and anticipated increase in climate refugees and resource wars. Finally, our brief consideration of pedagogical requirements will need to be operationalised, and to do so we will need to engage teachers and educators to design appropriate curricula for an uncertain future.

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