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Spatial Information Models as the backbone of Smart Infrastructure

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Climate change is perhaps the greatest challenge to our life on this planet, with energy and the scarcity of resources being major factors in shaping the landscape of decision-making in industry and public policy. In the UK, the building stock comes first, and transportation comes second in being accounted for carbon emissions. Hence, the efficiency of buildings and the urban network that ties them together needs to be treated as top priority in order to meet the targets set by Paris Climate Change Agreement. In public policy, the demand for strategies to address efficiency in green buildings and green infrastructure mobilized innovation in the construction sector, which had implications on the design, construction and operation of buildings. Similarly, in the smart cities and smart grid sectors, innovation was mainly mobilized to respond to challenges underlying transport planning, and to improve the efficiency in gas, electricity and water supply networks. Industry is leading the way to drive these innovations, but with no strong ground in building and urban morphology, there is a risk that any technologies applied might become redundant over time.

With the pervasive application of smart building and smart city models on different geographies, the challenge remains to be in the very infrastructure upon which smart city platforms are fitted and constructed, particularly when addressing long term and short term urban dynamics. Long term urban dynamics were traditionally a subject of intense research in urban morphology, complexity research, economics, entropy and catastrophe theory (Christaller, 1933; Allen, 1997; Pumain, 1998; Wilson, 1970; 2011; Bettencourt et al, 2007; Marshall, 2009; Strano et al, 2012), with the aim to underline what changes and what persists to change in cities over long periods of growth. This trend in urban research was recently diverted towards thinking and modelling sudden and short-term dynamics induced by the era of Big Data and the Internet of Things (IoT) and enabled by networks of sensors, citizen science, Geographic Information Systems (GIS), and web 2.0 technologies (Castells, 2011; Batty et al, 2012; Burdett & Rode, 2012; Dalton et al, 2013; Hudson-Smith, 2014; Yang, 2015; Bingham-Hall & Law, 2015; Partanen, 2015). Short term and real-time visualizations of how urban systems operate were proven to be crucial to understand the impact of major disruptions and to identify thresholds at which these disruptions cause breakdown. An understanding as such is a key to embrace these new technologies in the design and evolution of sustainable infrastructure, moving forward to smarter cities. The complexity, short-term and long-term dynamics, combined with the need for universal, integrated and systemic solutions in response to urban problems, are presenting major challenges to policy makers and planners as well as designers and industries (Collins, 2010). These challenges triggers questions of the type; how to adapt urban infrastructure in such a way as to optimize the performance and operation of cities as systems of systems and embrace the influx of visual and virtual information flows?

The representational models of Building and urban morphology (Marshall, 2009; Steadman, 2014; Batty, 2014), as well as Space Syntax (Hillier, 1996) would perhaps serve as backbone models for a standardized infrastructure to integrate smart city and smart building systems. Whilst the description of building and urban morphology is static, relying mostly on how built environment is represented and how information is annotated and associated with each element, the description of smart cities would often entail the dynamics of day-to-day transactions and citizen-focused scenarios. This calls for an advancement of theories on building and urban morphology and their representational schemes (Jeong, and Ban, 2011; Schultz and Bhatt, 2011; Duarte et al, 2012), to enable the adaptation of technology for sustainable urban futures. This would perhaps entail –for example- going beyond current practices in planning for accessibility (Rose and Stonor, 2009), to establish the link with energy consumption (Croxford et al, 1996; Park et al, 2013), and embrace the role of structural representations of urban morphology in the development of green buildings and smart cities (Stonor, 2016).

Rather than seeking simple answers through reduction and representation, there is a need to attend to the full complexity that characterizes infrastructure interdependencies (Al_Sayed et al, 2016; Batty et al, 2008; Al_Sayed et al, 2015; Al_Sayed and Penn, 2016), encompassing transport networks, energy, operation and maintenance, inter-operability, adaptation and resilience (Varga and Harris, 2015). Henceforth, the main objective for this themed issue is to highlight key contributions in the fields of building and urban morphology that need to be accounted for when building spatial information models for smart infrastructure.

The opening paper in this themed issue "cities as implements or facilities –the need for a spatial morphology in smart city system" covers both the building and urban scales. In this paper, Marcus and Koch introduced a new theoretical perspective to describe the role of built form in making cities smarter. Their perspective stems from the notion of "spatial capital" that accounts for the spatial constitution of built form and how it accommodates for 'diversity' and 'density' through facilitating the relations between people, and between artefacts or 'things'. Rather than reproducing the debate about technological 'implements' of smart city systems, the authors introduced the concept of cities as 'facilities'—that is, "as technologies that slow down, store and maintain energy as a resource for a variety of purposes". The notion of a 'facility' would perhaps be analogous to the concept of space as the 'machine' in Hillier's terms (1996), or the concept of "buildings are classificatory devices" in Markus's (1987) terms.

Marcus and Koch emphasized the cognitive and social dimensions of built form considering that smart technologies are devised to serve in the social and cognitive spheres. To that end, it is important to highlight that the spatial organization of a layout is highly shaped by the type of social organization that occupies it whether hierarchical or distributed. Extending Hillier's theorization about the "generic function" of space (1996), Marcus and Koch recognized that spatial organizations are more generic, in that they offer new opportunities for social relationships but they also exclude some possibilities. In their interpretation, the built form of buildings and cities might be considered as smart: since, it provides the physical medium for cognitive and social processes; whilst reserving the generic property of space allowing for flexibility, adaption and resilience in such processes.

The second paper in this themed issue "3DStock: A new kind of three-dimensional model of the building stock of England and Wales, for use in energy analysis" is focused on building information models. In a non-domestic energy epidemiology approach, Evans et al described the development of a new '3DStock' model, which visualizes the British building stock in three-dimensions. The '3DStock' model starts from a simplified 3D geometry of a building, and dives into modes of ownership through distinguishing 'premises' within buildings', and representing patterns of activities on different floor levels. The model also accounts for 'building archetypes', as well as relationships with neighbouring blocks, sites, and roads. Every building is associated with information about its material, age, construction, and energy consumption. The 3DStock is particularly useful for modelling the non-domestic building stock, which suffers from a higher level of complexity than the domestic building stock, since it is likely to embrace mixed use and separate premises. The geometrical/geographical structure of the model is assembled automatically from existing national data sets for England and Wales. The paper explained in detail some major difficulties in assembling building information from existing datasets, mostly due to inconsistencies relating to classification of data, missing data, and how information is recorded and monitored. However, the application of the model yields that it is possible to infer missing properties of buildings from existing datasets.

In the third contribution to this themed issue; "From paths to blocks: New measures for street patterns", we move to modelling block and street networks on the urban scale. In this work, Barthelemy introduced a set of methods for classifying street networks as well as block size and shape, highlighting the role of shortest routes in the evolution of street networks. The impact of shortest routes in street networks revealed two distinct characteristics of urban growth: one of densification, marking an increase in the local density of urban texture, and one of exploration, marking the expansion of street network toward non-urbanized areas. These processes were observed in the natural development of the Groane region, and in Paris. Barthelemy also proposed that the planar networks of streets could be characterized through comparing the simplest paths, with the fewest terns. These comparisons exposed different structures in street networks, in the rail networks of Australia and the UK, and showed high correlations between street and water systems in Nantes. The analysis exposed patterns of growth and evolution in street systems that revealed a higher tendency towards randomness, compared to the hierarchical natural networks in biological systems.

For classifying urban blocks, Barthelemy used the conditional probability distribution of the shape factor of urban blocks in order to define what constitutes the fingerprint of a city. He generalized his methods on 130 cities to come up with four broad families of cities characterized by different abundances of blocks of a certain area and shape. This classification helped identify differences as well as commonalities between cities across different geographies. It appeared –for example- that the area distributions of blocks have different shapes for small areas, but display fat tails that decrease following a power law distribution.

The fourth paper in this themed issue; "Urban space production assessment: Towards an understanding of morphogenesis in street-networks", authored by Serra et al. used a combination of Space Syntax and GIS techniques to model and classify urban form. Serra et al. investigated the role of local network properties of street configurations in influencing the global properties of urban structures. They tested their methods empirically on the Oporto metropolitan area, where they isolated new streets that have emerged over 60 years of historical growth and they classified them into different typomorphologies using clustering techniques. They investigated how these emergent structures incrementally change the global network properties of street networks. Akin to Barthelemy's approach, Serra et al. re-emphasised the role of urban blocks in defining the characteristic features of urban form, by representing them with 'network cycles'. They attempted combining both network and block descriptions of cities through empirically classifying the typomorphologies of street patterns into planned (motorways), and unplanned structures. The latter was also classified into linear (streets that do not outline an urban block), and cellular (streets that outline an urban block). The analysis revealed that cities are predominantly constituted of linear street elements. Serra et al. added yet another classification of street networks, that is; conjunctive networks (new streets that have high level of connectivity with their neighbouring structures), and disjunctive networks (isolated clusters of new streets with very little connectivity to existing structures). Building on this empirical analysis, they outlined a set of classifications of street typomorphologies based on size (small/big), cyclicity (linear/cellular), and connectivity (conjunctive/disjunctive).

The last paper in this themed issue, "Partners in the street ballet: An embodied process of person-space coupling in the built environment" addressed the human condition with reference to A.I. and situated cognition. Alasdair Turner investigated building and urban infrastructure from the perspective of users focusing on the type of mechanisms underlying human cognition. For that he built a simple agent-based model or automata that moves in response to the visibility field available from its location. Turner attempted to rule out what type of moves or steps are more likely than others in natural movement of pedestrians. For this purpose, he advanced his cognitive agent-based model to include elements of evolutionary learning and memory. To be more specific; the evolved agents were able to sample the length of line of sight from a location, and thus build a relationship between the agent as a sensorimotor representation of a person and the axial map as a representation of a spatial layout. Turner realized that, by encoding memory in his automata, the resultant patterns of agent movement did not plot good correlations with observed patterns of movement and occupancy. The correlation scores were much lower than the original simple automata, and his earlier evolved automata. Turner's experiments indicated that the evolved automata embodied a mathematical person–space relationship that joins visual affordances of the built environment with motor action.

Towards a spatial information modelling architecture for smart infrastructure

An understanding of how smart systems operate is anchored in their interdependencies both on the building and city scales. In Marcus and Koch proposition, the built environment acts as an entity to facilitate the structure that brings artefacts or 'things' together and determine the possibilities for interactions between them and between people. The configurations would also facilitate the size, constitution, and locations of social co-presence. Marcus and Koch argued that an increase in the intelligibility of the built environment would offer a better infrastructure for information flows and a higher efficacy for smart city systems. In the same way, the building typology embeds information about social and cultural practices and facilitates the exchange of information, and the storage and maintenance of energy.

Through the 3DStock model, Evan et al demonstrated exactly how buildings might be modelled as to account for the multiplicity of factors that contribute to energy performance. The 3DStock model was used to analyse –often by using parent-child associations- the relationship between energy consumption and built form (building volume and surface, and building depth as measured in plan). It also accounted for other factors such as type of activity, building occupancy, type of servicing systems (e.g. heating, lighting and air conditioning), the age of a building, construction, and materials (e.g, the area of glazing).

On the urban scale, Barthelemy's models of street networks, and Serra et al. classifications of street typomorphologies could be used to define critical points in the graph network that are likely to persist during urban growth, and elements of the network that will continue to be in a dynamic state. Their findings could have implications on grading investment in infrastructure as to prioritize elements that appear to be resilient and essential to the functioning of urban form throughout its historical development (e.g. simplest paths or shortest paths in the street network). Another important aspect would be to highlight prevalent block properties, and perhaps standardize and customize certain segments and units of smart networks in accordance with these properties. These distinctions could inform industry and policy-making decisions concerning smart infrastructure investment.

And finally, on the human scale, Alasdair Turner investigated the nature and mechanisms of individual movement behaviour and how they are influenced by the physical layout of the built environment. Turner acknowledged the role of experiential preferences as well as social, economic and political factors, but his focus was mostly on what type of cognitive strategies individuals need to set in order to navigate the spaces afforded by the physical environment. Within this context, his studies enriched the body of knowledge that adheres to smart citizen, particularly in relation to individuals' cognition of the environment.

At the essence of these proposed models, whether on the urban, building, or human scales, there is the intuition about simplified ways in which we could describe, model, and classify the information that constitutes the built environment. By exposing these simple descriptions, and their role in short-term and long-term urban dynamics, it is possible to build a more robust information modelling architecture for built form. It is also possible to establish a more healthy relationship between active users, the environment, and technology. However, one needs to acknowledge that the complexity of social structures goes beyond any simplified modelling approach. One also needs to acknowledge that scientific models might retain value in the social context. It is often difficult to foresee how this value might impact life in buildings and in cities, since most of these models come as a response to a well-defined set of problems or requirements. For that perhaps there is a need to devote a whole body of research to find sensible ways in which social relationships might be encoded in building and urban information models, and envisage the consequences of these models on human life.

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