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# Smart and resilient cities
## How can big data inform spatial design and planning for urban resilience?

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*Amongst other vectors of change, the development of cities as complex socio-technical-environmental systems is influenced by two notable driving forces: the accelerated development of smart city technologies enabled by the abundance pervasiveness of Big Data and the challenge of resilience to an increasing number of shocks and stresses driven by climate change and urbanisation. Recognising potential synergies between these two driving forces, the paper explores ways in which Big Data can contribute to the translation of systemic resilience targets into principles of spatial transformation and, as a result, to a better evidence base for urban design and planning decisions. To that end, the paper discusses the relationship between Big Data, urban design and planning, and urban resilience. It highlights how resilience-building is enabled by Big Data through, such as evidence-based design, spatial data visualisation and cross-scalar design. The paper also provides an overview of challenges that are brough by Big Data to urban resilience-building. The discussion ends with how Big-Data-driven urban resilience can be an approach that is complementary rather than alternative to traditional practices.*

**Introduction**

Cities as complex socio-technical-environmental systems are facing two interlinked challenges: the abundance and pervasiveness of data enabled by accelerated developments in ICT and the challenge of resilience to an increasing number of shocks and stresses driven by climate change and urbanisation. These two challenges are at the core of two urban development paradigms that guide urban design and planning in relative disconnection: The Smart City and The Resilient City. It can be argued that these two paradigms overlap and that Big Data, mostly fuelling the Smart City movement, can provide valuable input for building urban resilience. With a shared systemic understanding of the urban environment, both signal the need for evidence-based design and planning.

This paper explores «How can Big Data help urban designers and planners improve urban resilience?» and discusses «To what extent is Big Data necessary in addition to current knowledge and practices of resilience building?» The following sections provide an overview of the impact of Big Data on urban transformations in the context of urban design and planning in general and on resilience-building in particular. The paper concludes with a discussion of challenges and opportunities of employing Big Data in resilience-building through urban design and planning.

**Big Data and urban transformations**

In a rapidly developing data economy, Big Data play an increasingly prominent role. Large volumes of data, mostly streamed through routine sensing and crowdsourcing, capture spatial and temporal information in great detail, progressively complementing traditional datasets underlying decisions on urban transformations (Sim & Miller, 2019). This kind of granular data is unprecedented, as it can provide insights into short-term dynamics in cities (e.g. hourly pedestrian movement patterns in cities based on GPS and real-time transportation data), potentially helping urban designers and planners transform the urban environment in a less ad-hoc and more evidence-based manner (Batty, 2013).

Combined with advances in the Internet of Things (IoT), machine learning (ML) and artificial intelligence (AI) (Allam & Dhunny, 2019), as well as developments in computational toolkits (Boeing, 2019), Big Data enable a multitude of Smart City applications with a wide range of descriptive, predictive, prescriptive and discursive functions (Data-Pop Alliance, 2015). Applications include using Big Data for designing an planning urban environments that encourage human health and well-being (Miller & Tolle, 2016), evaluating human perception of—and emotional responses to—urban spaces through Flickr or Twitter data (Li et al., 2016), understanding and enabling self-organised urban transformations (Xu, Yan, & Huang, 2017), measuring street walkability using ML algorithms and Google Street View imagery (Yin & Wang, 2016), and agent-based simulations improved by Big Data (Scheutz & Mayer, 2016), to name a few.

In this context, the fields of urban design and planning are getting acquainted with the opportunities and challenges that Big Data bring for urban transformations. Urban design is commonly defined as "the process of making better places for people than would otherwise be produced [and it is] primarily concerned with shaping urban space as a means to make, or re-make, the 'public' places that people can use and enjoy" (Carmona, Heath, Oc, & Steve, 2010, p. 3). This definition extends beyond the scope of the Smart City paradigm, primarily concerned with optimising the performance of urban systems, to emphasise the qualitative and experiential dimension of the urban environment. With an understanding of the urban environment as shaped by the combined flows of people, goods and information (Batty, 2013), urban designers and planners are concerned with guiding the morphological (i.e. spatial, physical) transformation of cities at multiple spatial and temporal scales. Moreover, recognising that the quality of urban spaces influences and is influenced by the use of technology (Carmona, 2018), urban design and planning needs to consider sensing and perception of a place, in addition to improvements in the quantitative understanding of urban systems provided by Big Data.

Although there is interest in "data-driven urban morphology" (Erin et al., 2017 and Moudon, 1997 in Boeing, 2019, p. 2), Big Data remains an underexploited topic in urban morphology (Crooks et al., 2016). Most developments have been made in the interdisciplinary field of urban data science, aiming to translate big data into information that is relevant and understandable within and across disciplines. As a specific geographic application of Big Data, urban data science focuses on spatially explicit problems (Singleton & Arribas-Bel, 2019), such as the relationship between land rent and urban form (Wu, Wang, Zhang, Zhang, & Xia, 2019) and makes extensive use of spatial (or geographic) Big Data.

Spatial Big Data has emerged mostly through user-contributed open geographic data such as OpenStreetMap (OSM), for which gradually temporal information becomes available as well (Boeing, 2019). Combined with tools to query, analyse and interpret, spatial-temporal Big Data provides a promising base for applications in the field of urban morphology. It enables applications that were not possible with traditional geographic data, such as cross-city and cross-time comparisons for a better understanding of similarities and variations between urban environments on a global scale. Fuelled by spatial-temporal Big Data, the tools for urban analytics that can provide a networked and multi-scalar understanding of urban systems behaviour are quickly evolving to support decisions for short-term crises (Batty, 2013; Boeing, 2019). Examples include applications of the Space Syntax theory (Aschwanden, 2016) and tools such as OSMnx (Boeing, 2017), meant to help designers and planners to understand complex urban spatial configurations by means of street network analyses and data visualisation.

Data visualisation is an important component of data science, as it is essential for making sense of Big Data. As such, data science is well-aligned with the visual culture of urban design and planning (Boeing, 2019) tasked with the need to represent complex urban dynamics in a visually understandable way. Augmenting reality with multi-source, multi-scale, multi-time data combined in visual dashboards enabled by Big Data, facilitates better urban design and planning (Tunçer, 2020). Such visualizations can aid the integration of qualitative (interpretive or narrative) and quantitative (data-driven) perspectives in urban morphology (Boeing, 2019) necessary for urban design and planning decisions.

**Big Data and urban resilience**

Cities as complex socio-technical-environmental systems are subject to high levels of uncertainty and, in the face of climate change and accelerated worldwide urbanisation, they are exposed to disturbances of increasing frequency, magnitude, and variation. Hence, urban sustainability depends on urban resilience, that is, on the ability of cities to sustain, improve and innovate their key functions – through absorbing, reacting to, recovering from, adapting to or reorganizing – in response to chronic stresses, abrupt shocks, and disruptions (4TU Centre for Resilience Engineering, 2020). In this context, urban design and planning needs to consider resilience-building in shaping future urban environments. Yet systemic resilience targets are difficult to be translated into spatial transformations. Advanced urban analytics powered by urban Big Data can play an important role in attaining that translation by revealing patterns in urban systems dynamics that are difficult to understand otherwise (e.g. the level and location of extra spatial capacity needed in a network of public spaces to respond to certain disruptions, such as floods, pandemics or failures in transport services). It can reveal patterns in large volumes of data, and it can increase prediction capacity, thus providing better evidence on both acute shocks and chronic stresses occurring in urban environments.

With its 'three Vs'[1] – volume, variety and velocity – (Batty, 2016), Big Data can have a significant contribution to building urban resilience. First, with a better understanding of complex urban dynamics and evidence brought by Big Data, urban design and planning can be more integrated and strategic. By integrating a large volume of data, planners can gain a holistic understanding of the urban environment in question and can identify key spaces of vulnerability that require strategic intervention. For instance, a good understanding of emergent, self-organizing processes in relation to resilience in cities can inform decisions on where, whether, how much and what kind of actions should be taken, including inaction, subtraction or actions that have a desirable effect if a small amount of stress is induced (see the spatial-hormetic approach by Forgaci & van Timmeren, 2014a). Second, besides its quantitative advantages, Big Data can provide designers and planners with a wide range of qualitative insights about citizen behavior, needs and desires regarding urban space. Citizen science applications can improve response to disasters and increase the level of citizen participation in the resilience-building process. And third, if resilience-building has occurred on a long term in a trial-and-error fashion, advances in Big Data and urban analytics provide insight on resilience in much shorter time spans (e.g. mobile applications in which citizens and authorities interact to mitigate the impact of a disturbance, shock or chronic stress). The quality of spatial models, simulations and scenarios can be improved through Big Data, increasing preparedness to acute shocks and improving capacity to detect chronic stresses.

Resilience needs to be understood in a both place-based and generic manner. On the one hand, resilience needs a good understanding of location-specific threats to resilience and of the vulnerabilities of the local population and system. On the other hand, certain properties can be considered generic and transferrable from one urban environment to another. Redundancy, diversity, modularity and self-organization are examples of properties which are widely considered general properties of resilient systems (Carpenter et al., 2012) and which can be translated into properties of general urban resilience relevant for urban design and planning (Forgaci & van Timmeren, 2014b). Operationalizing general urban resilience properties requires data and tools of sufficient quality and size. Cross-city comparisons of spatial configurations enabled by spatial-temporal big data, such as OSM, can reveal morpho-dynamic properties that influence general urban resilience and hence can inform transferrable urban design and planning principles targeting resilience.

All in all, there is a growing need for planning support systems for urban resilience that are fully sentient (Deal, Pan, Pallathucheril, & Fulton, 2017). Established principles of resilience can be aligned with the emerging opportunities of the Digital (or Smart) City, but this will result in a wide range of challenges (Colding, Colding, & Barthel, 2020).

**Challenges**

The perspective presented in this paper recognizes the pervasiveness and ubiquity of Big Data and focuses on identifying opportunities at points of convergence between the Smart City and Resilient City paradigms. Moreover, it acknowledges that Big Data does present a number of technical, methodological and ethical challenges that must be considered in urban design and planning.

Technical and methodological challenges mostly revolve around integrating Big Data from multiple sources, multiple sectors, and multiple spatial-temporal scales, as well as ensuring computational capacity to store, analyse and interpret Big Data. Integrating Big Data from different sources and with traditional data sets remains a challenge. If *access* to data was a major concern until recently, that concern is gradually diminishing with the increased availability of open data (e.g. OSM data) and the greater challenge of *combining* and *making sense of* ever-growing and diversifying Big Data. Integrating different data sets can be potentially useful for understanding interdependencies between different systems (Deal et al., 2017) and responding to short-term disruptions (Batty, 2013).

Notably, integrating qualitative aspects of the urban environment and quantitative information originating from Big Data is a great challenge that require broad, inter-disciplinary approaches and advanced technical knowledge. Streamlining such approaches and making them more accessible to practitioners of urban design and planning is yet to be achieved. The visual culture of urban design and planning augmented with advanced (big) data visualisation presents a potential way forward for integrating mixed quantitative and qualitative perspectives in urban design and planning. All in all, urban design and planning require a better integration with the field of data science, either through interdisciplinary approaches involving data scientists or through increased awareness a widened skill set in the practice of urban design and planning that includes analysis of spatial Big Data. How much knowledge, skill and awareness is and could be achieved in practice requires further insight.

From a resilience perspective, a number of concerns arise in regard to the use of Big Data. As resilience is a complex systems property, how to *build* resilience remains

an open question. Many practices and technologies of resilience-building are 'low-tech', as they have developed through a slow evolution, based on knowledge gained through long-term processes of trial and error and adaptation (see, for instance, a discussion of social resilience in the case of elevated walkways during 'acqua alta' of Venice in Forgaci & van Timmeren, 2014a). Although advances of the Smart City paradigm, fuelled by Big Data, promise to provide evidence for resilience-building in considerably shorter timespans, urban designers and planner need to integrate those different modes of knowledge. The emergence of computational toolkits opens up a new era for evidence-based urban design and planning; yet synergies, complementarities and the transition between traditional and Big-Data-driven – or low- and high-tech – practices remain an important part of resilience-building. As there are several ethical concerns about the privacy implications of the transition to Big-Data-driven practices, there are considerable efforts to shift to an approach in which citizens are sensors rather than sensed (Doctorow, 2020), are well-informed, and have the freedom to decide whether and what data they share.
Another resilience-related concern is dependency on Big Data (Walloth, 2016). Even though Big Data may inform spatial decisions on resilience-building better, over-dependency on Big Data in the future might lead to reduced resilience in case of disruptions in data streams. Therefore, urban design and planning should make use of Big Data not only for systems optimisation and efficiency but to increase resilience to data stream disruptions as well. Moreover, from a social resilience perspective, continuous engagement, participation and co-creation allow for sustained citizen awareness, knowledge and innovation that do not depend on the availability of data. Augmented with Big Data, the collective knowledge and bottom-up decision power of citizens can contribute to better-informed, place-specific and timely resilience-building processes.

**Conclusions**

This article explored the potentials of Big Data in the field of urban design and planning in general and in its application in the domain of urban resilience in particular. As urban resilience is a *systemic* property – that of a city as a complex social-technical-environmental system – , it needs to be translated into resilience-building *spatial* transformations by urban designers and planners. The paper posits that Big Data can aid such efforts of 'translation' as it provides the possibility of an unprecedented evidence base for complex urban transformations. Potential advances in the field of urban morphology augmented by spatial-temporal Big Data as well as data visualisation were presented as potential additions to the toolset of designers and planners. Resilience-building aided by Big Data would benefit from more spatial-temporal evidence, would allow for easier modelling, prediction and testing in a short time, and could be carried out in a more strategic manner at multiple scales (e.g. by underpinning decisions on the locations of strategic interventions in a city, metropolitan area or region). The last part of the paper highlighted a number of challenges arising from the use of Big Data. Most challenges are a matter of integration: between different data sources, sectors and spatial-temporal scales, between quantitative and qualitative perspectives. Amongst the next steps in addressing those challenges, the paper recommends a better integration between urban data science and the fields of urban design and planning, seeking for complementarities, synergies, as well as a better understood transition between traditional and Big-Data-driven practices.


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# Note

[1] A fourth 'V' of Big Data, veracity, is not included in this description of Big Data, but it is nevertheless essential for establishing the quality and authenticity of data (Ospina, 2018).

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