

# Evidence-Informed Decision-Making in Multi-Stakeholder Settings: The Case of City Digital Twins for Urban Health Planning and Smart Infrastructure Management

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## Abstract

*This paper shares initial findings on how data, modelling and evidence is used to inform decision making in the Cambridge city region, UK. It discusses fragmentation of governance across the vertical, horizontal and sectoral/systemic dimensions, as well as the impact of this fragmentation on data collection, access and evidence formation and its use along the decisionmaking process. The investigation is framed by how city digital twins, the latest evolution of urban analytics, could and should be designed and implemented in order to help overcome fragmentation of data and governance. The findings inform the development of a city digital twin prototype for the Cambridge region. Addressing issues related to the dispersion of powers, responsibilities and expertise across a multi-actor governance landscape is essential in improving the use of evidence in Cambridge, and must be considered as a priority for the design and implementation of the city digital twin prototype.*

**Keywords** – urban governance; urban modelling; planning; city digital twin

## 1 Introduction

This paper addresses the following question: how might existing urban governance systems influence the design and implementation of city digital twins (CDTs)? City digital twins are conceptualised as next-generation urban modelling tools which make use of ubiquitous data produced through various digitalisation trends in the built environment and beyond. This paper presents early results from the case study of a CDT prototype currently under development for the city of Cambridge.

The digital twin concept is not new: Nasa used digital replica-based simulation environments for their Apollo missions back in the 1970's. The term was coined in the early 2000's in the context of manufacturing and Product Lifecycle Management (PLM). In the United Kingdom, the current enthusiasm surrounding digital twins for asset management has been driven by the National Infrastructure Commission's report on 'Data for the Public Good' (NIC, 2017) which set out the plan for developing a UK national

infrastructure digital twin. Subsequently, the Digital Framework Task Group (DFTG) was established as part of the Centre for Digital Built Britain (CDBB) as the University of Cambridge to contribute to delivering the goals identified by the Commission. In their recent report, the DFTG defined digital twins as '*realistic digital representations of physical things*' (assets, processes or systems) in the built and natural environment which support improved decision-making (Bolton, Enzer, & Schooling, 2018). Following the DFTG's definition, for the purpose of this paper CDTs are defined as *realistic* digital representations of physical city systems, assets and processes providing digital simulation and management environments to aid decision-making in city planning and management. However, defining CDTs is still work-in-progress and needs further refinement, critical thinking and input from a broader set of disciplines.

We contend that if CDTs are to contribute to the development of smarter cities, they must be orientated towards delivering social, economic and environmental outcomes that meet citizens' needs and respond to contemporary urban challenges (cf. Nochta et al., forthcoming). These include (among others) climate change mitigation and adaptation, urban sprawl, spatial inequality, poor air quality, congestion and strain on infrastructures and services. Digital tools, including CDTs, will not offer straightforward solutions to either of these. However, they may provide a chance to look at the challenges afresh, and to establish new governance structures and mechanisms which are better equipped to cope with them. Thus, CDTs must be designed and implemented with an explicit aim of mitigating against structural failures in contemporary urban societies which produce (and re-produce) these challenges. This paper focuses on a typical contemporary failure that hinders the development of holistic responses to complex urban problems: organisational/institutional fragmentation and silo-isation.

The rest of the paper is structured as follows. Section 2 provides an overview of the existing academic literature that underpins the governance perspective on CDTs. The research design and data collection methods employed in this study are presented in section 3. Section 4 provides an analysis of the data collected and highlights fragmentation along various dimensions. Finally, conclusions are drawn

regarding the impact of fragmentation on the use of evidence for strategic urban planning in Cambridge in section 4.

## 2 Literature overview

The literature overview focuses on gathering existing knowledge on how contemporary issues of governance might, as they unfold locally in specific cities, impact upon the use of evidence for decision-making and vice versa. Improving the processes of evidence-informed decision-making in urban planning must be a key priority for the design and implementation of next-generation urban modelling tools, in particular city digital twins (CDTs).

Since the dawn of urban modelling in the 1950's and 1960's researchers and planners have been continuously debating the usefulness and impact of models to provide evidence for decision-making about planning policies, strategies and interventions. The early enthusiasm for modelling cities decreased parallel to the emergence of a more 'business-like' approach to governing in the 1980's and 1990's. While the first urban models were developed in a period when *'rapid advances in science and technology ... seemed to hold out the promise of a more rational 'designed' set of public policies and institutions'* (Pollitt & Bouckaert, 2011, p. 6), the potential of models to meaningfully support urban planning has been questioned in the post-modern era. Critics pointed to the high degree of simplification of urban processes necessary to simulate them; data requirements and the complications involved in collecting data to feed the models; and inadequately handling human behaviour and its implications – to mention a few (Batty, forthcoming; Lee, 1973).

Despite the criticisms, the modelling of urban systems and infrastructures has become part of planning decision-making in many cities around the world. The extent of influence of modelling results on the decisions made nevertheless remains debatable as planners generally rely on a broader range of knowledge including past experience, general professional knowledge, formal education, and interactions with various decision makers and community members (Krizek, Forysth, & Slotterback, 2009); as well as intuition, instincts and inspiring anecdotes (Jin, forthcoming).

Recent advances in the technologies, techniques and theories which underpin urban modelling sparked renewed interest in models for analytics and management. The currently unfolding '4th Industrial Revolution' is an opportunity to address some of the aforementioned criticisms: moving from a period of relative data scarcity to an era of 'digital abundance' may enable more accurate modelling predictions based on large-scale, dynamic and better-quality data capturing urban processes in more detail

than it was previously possible. In parallel to technological advancement, there is a growing recognition for the need to generate better evidence for the planning and management of cities to deal with pressing urban challenges. Next-generation urban modelling tools (specifically, CDTs) must make use of these developments.

However, unpacking what 'better evidence' entails remains a challenge. Future investigations must involve not only the 'quality' of the evidence itself but also its production and use along the decision-making process. This way we can contribute to the development and design and CDTs by specifying a broader set of requirements compared to the mainstream discourse.

Contemporary and emerging technologies in data collection, processing and analysis can make a substantial contribution to enhancing the accurateness and credibility of modelling results – and therefore improving the quality of evidence used in planning decision-making. This however does not guarantee that models and CDTs will be perceived as functional, purposeful and trustworthy tools (cf. (Bolton, Enzer, & Schooling, 2018) to aid decision-making processes by the societal actors involved in these.

From a governance perspective, CDTs must also contribute to addressing pressing urban challenges and to capacity building in existing governance systems to address those challenges more effectively and efficiently. Cities around the world are grappling with problems of growing population (and growing needs to be served), increasing spatial inequality, economic stagnation and the need to act on climate change. In parallel, the urban governance systems currently in place are often inadequate to deal with such issues that cut across traditional organisational, institutional, sectoral-systemic and other silos. It thus seems necessary to better understand which silos, and how, impact upon developing more holistic responses to locally relevant urban challenges.

Public policy and administration scholars usually focus on fragmentation (and silo-isation) along two dimensions: vertically, across different levels of government in 'multiscalar' governance arrangements; and horizontally, among different segments of societies belonging to the public, market or the third sector (Hooghe & Marks, 2003). It is often argued that the vertical and horizontal dispersion of powers and responsibilities resulted in issues with societal coordination in recent decades which, among other things, manifests itself in the inability of contemporary governance systems to address cross-cutting issues.

Multi-disciplinary research around urban sustainability and resilience also highlights another form of fragmentation. This work sees cities as complex systems of systems (Rogers, 2018) which (infrastructures such as transport,

energy, water; and services including healthcare, social care, education, etc) function relatively autonomously, but at the same time also impact upon one another through complex patterns of interaction. Such systems are usually organised in vertical sectoral silos and therefore coordination among them on the city scale is inherently problematic.

In order to counteract the negative effects of fragmentation and silo-isation, contemporary discourses in public policy, administration and management often refer to concepts of networks, partnerships, joined-up government or participation. A large body of literature developed in recent decades around policy networks, inter-organisational service delivery, and network governance (Klijn & Koppenjan, 2015). This literature however so far has largely failed to account for and assess the potential of digital tools to support more joined-up decision-making. Arguably, many digital tools, such as CDTs, provide new channels to improve integration and interoperability across the organisational landscape – and by doing so may support collaboration.

In the following we present a case study of the development of the CDT prototype for Cambridge, UK and discuss the currently existing governance structure relevant to the CDT prototype and expose vertical, horizontal and sectoral silos; the ways in which fragmentation is currently addressed and the impact of this fragmentation on evidence-informed decision-making in urban planning (and aspired city-level outcomes). This information is used to develop recommendations for the design and implementation of the Cambridge CDT prototype. We argue that considering these recommendations is necessary if CDTs are to move beyond mere ‘hype technology’ (Rogers, 2019).

### 3 Methodology

The challenges to be addressed by the Cambridge CDT (currently under development through a research project at the Cambridge Centre for Smart Infrastructure and Construction) were decided through a workshop jointly organised by the research team at the University of Cambridge and the Smart Cambridge team. The workshop involved representatives of various local government organisations: Cambridge City Council, Cambridge County Council, the Greater Cambridge Partnership (GCP) and the Cambridge and Peterborough Combined Authority (CPCA). Participants identified two interconnected problems: tackling congestion and improving air quality. These transport-related issues also have a knock-on effect on the energy infrastructure as a main strategy to improve air quality is the promotion of electric vehicles. Providing appropriate charging infrastructure however is currently hampered by the very limited capacity of the electricity grid to host charging stations. In turn, grid capacity issues also

delay new residential and commercial developments and therefore affect the local economy.

Local commitments exist to reduce car use by 24% by 2031 compared to 2011 baseline numbers while improving air quality and keeping pollutant concentrations (NO<sub>2</sub> and PM) within the safety limits set by national policy. These improvements will need to take place against a project 15% population growth between 2011 and 2031, and other economic and spatial development targets. Delivering on these targets requires coordination and joint working across various local government levels (city/district, county, metropolitan, national); the public sector and private sector stakeholders (e.g. Cambridge University, service providers, consultancies, employers) and citizen groups (e.g. Smarter Cambridge Transport, CamCycle). Links and interdependencies between infrastructure sectors and services (e.g. transport, energy, planning/housing, telecommunications, air quality) must also be mapped and accounted for.

Data collection focused on qualitative information gathered from primary and secondary sources. Two workshops and over twenty interviews have been carried out with local stakeholders from the public, market and third sectors. We attended and observed community forums to understand residents’ views and public consultation strategies. The data collected from primary sources has been complemented with national and local policy documents, technical reports, and academic papers on urban analytics, city planning and digital twins.

## 4 Data analysis

### 4.1 Vertical fragmentation across scales

There are three layers of authorities below the UK national level in the wider Cambridge city region: city/district, county and metropolitan. Figure 1 shows the different local authorities that are relevant to the case study area.

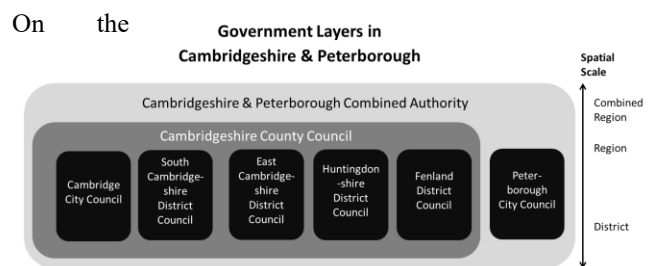


Figure 1. Government layers in the Cambridgeshire and Peterborough area ranging from local to regional.

metropolitan level, the Cambridge and Peterborough Combined Authority (CPCA) brings together the various local authorities from the region, including the City

Councils of Cambridge and Peterborough, the District Councils of South Cambridgeshire, East Cambridgeshire, Huntingdonshire and the Fenlands. The CPCA includes the 'Business Board' which is the Local Enterprise Partnership (LEP) for the area. The Business Board involves representatives from local authorities, the University of Cambridge and agriculture and industry. The CPCA has been set up relatively recently (in 2017) with a 'weak mayoralty' - all decisions made on this level have to be approved by the CPCA board. The strategic leadership role of the region has been assigned to the CPCA and the Mayor including the transport strategy and economic development targets. Nevertheless, due to its relatively short life-span, political differences and the dispersion of powers across the local authority levels, including that of financial resources between the CPCA and the Greater Cambridge Partnership (GCP), practical outcomes are lagging behind.

The GCP has been established by the UK Central Government via the City Deal, assigning funding and powers to invest in infrastructure to accelerate growth in the region (up to £1 bn between 2014 and 2029), and to deliver 44,000 new jobs and 33,500 new homes in the region. The GCP involves officers from Cambridge City Council, Cambridgeshire County Council, South Cambridgeshire District Council and the University of Cambridge.

The Cambridgeshire County Council involves all local authority areas of the CPCA with the exception of Peterborough City Council. Being an established regional authority, the County Council is currently still undertaking many strategic functions nominally assigned to the Combined Authority (for example, in the case of transport planning and management).

In summary, local authority powers in the region are dispersed among multiple authorities which often have overlapping responsibilities. Strategic powers, implementation and financial means are separated, adding to the complexity. This may result in disconnect between the strategic plans and initiatives on the ground, as well as contradictory or incompatible aims being pursued by different local authorities.

#### **4.2 Horizontal fragmentation across segments of society**

Besides the public sector actors presented in the previous section, practical outcomes of city planning and management activities are also being influenced by a variety of actors from the market sector as well as civil society organisations in Cambridge. While these organisations are not part of formal public sector decision-making, they exert influence in various ways.

In terms policy-making, private sector companies are involved in the CPCA Business Board, evidence production (e.g. consultancies, the University and its spinoff companies) as well as lobbying (e.g. Cambridge Ahead, Cambridge Connect, Cambridge Network). Lobbying is not confined to private companies: many citizen groups are also active in particular in the transport and housing sectors (e.g. CamCycle, FeCRA) but less so in debates around energy. Community groups also engage with the private sector directly (e.g. developers, large employers) to influence their transport-related strategies and to understand the projected growth (e.g. in traffic, housing, employment).

Evidence production, especially the production of predictions through various forms of modelling exercises is most often undertaken by consultancy companies. Different local authorities typically work with different consultancies: Cambridge City Council is in a contractual relationship with Cambridge Environmental Research Consultants (CERC) to conduct air quality modelling – while air quality monitoring and data collection is managed by Ricardo plc. The County Council's transport modelling is undertaken by Atkins and Mott MacDonald. The Greater Cambridge Partnership recently worked with Arup, while the evidence base for the Cambridge Autonomous Metro (one of the flagship projects of the Mayor) was produced by Steer Consultants commissioned by the CPCA. Cambridge University and its spinoff companies also work regularly with local authorities in econometric, land use and transport modelling.

On the operational level, the management of urban infrastructures and service provision have been contracted out to private companies (e.g. Stagecoach, UK Power Networks, various developers). Local public transport is dominated by bus, and to the lesser extent trains. Bus operators in the area include Stagecoach and Whippet Coaches Ltd (local company originally, sold to the Australian-international Transit Systems in 2014). The main rail companies connecting Cambridge to the surrounding areas and to London are Greater Anglia and Thameslink. The railway station is operated by Greater Anglia. In the energy sector, electricity and gas distribution networks are operated by UK Power Networks. Recently, local stakeholders (Local enterprise Partnerships - LEPs) in the region have started pulling resources together to support local low-carbon energy production: the Greater South East Energy Hub was established in 2018.

Different levels of government have developed different forms of public consultations to supply grounded evidence for policy-making. These include consultation through city wide meetings, Local Liaison Forums, online surveys (e.g. the Big Consultation Survey by the Greater Cambridge Partnership) and consultations (e.g. by local politicians). Despite the wide range of engagement methods, citizens'

voices have had limited impact on policy and practical outcomes so far.

In conclusion, a variety of actors are involved in diverse ways along the decision-making processes relevant to city planning and management in Cambridge. Practical and policy outcomes are therefore best understood as resulting from complex processes of knowledge production, negotiation and deliberation involving multiple actors from the public, market and the third sector.

### 4.3 Sectoral silos across city systems

The city systems relevant to our case study involve transport; energy; spatial planning land use and housing; air quality; and telecommunications. The main legislative and regulatory powers in most sectors are retained by the Central Government in England. Central government sets out its planning policies for England in the National Planning Policy Framework (MHCLG, 2019). Legislation and regulation of the energy sector sits with the Department of Business, Energy and Industrial Strategy and Ofgem.

The main locus of decision making on planning matters is the at the district level. The Cambridge Local Plan sets out the planning framework to guide the future development in Cambridge until 2031 (Cambridge City Council, 2019d). Cambridge is planning to grow by 14,000 new homes in the city by 2031 (Cambridge City Council 2019c). The latest Cambridge Local Plan, adopted in October 2018, sets out where the growth areas are located and what infrastructure investments are needed to foster growth (Cambridge City Council, 2019d). Cambridge City Council and South Cambridgeshire District Council work closely together as South Cambridgeshire ‘wraps around the city’ and some designated development areas cross the city boundary (Cambridge City Council, 2018b). Cambridge City and South Cambridgeshire have a joint planning team that collectively work on the local plans for the two councils (Cambridge City, 2018c). Housing development is undertaken by the private sector, by developers such as Marshall's and Hill. The University of Cambridge has also developed large greenfield sites in West Cambridge and North West Cambridge, for university research building and housing.

Responsibilities for transport infrastructure are spread across different government layers: county, combined authority and national. The Greater Cambridge Partnership plays a role as funder of transport interventions. Public transport services were privatised and deregulated across Great Britain (bar London where services were only privatised) in the 1980s. Rail and bus services in Cambridge are run by two private companies, Stagecoach and Whippet. In 2014, Cambridgeshire County Council published the Transport Strategy for Cambridge and South

Cambridgeshire (TSCSC). The TSCSC sets out how investment in transport would support growth and development goals set out in the Local Plans to 2031 (Cambridgeshire County Council, 2019). The TSCSC is also the basis for the GCP transport investment programme worth £100m to 2020 and with the potential for a further £400m after 2020 (GCP, 2019). Under Bus Services Act 2017, combined authorities with elected mayors such as the Cambridgeshire and Peterborough Combined Authority has the right to take up bus franchising powers (Butcher, 2018). These powers would allow the CPCA to manage the bus network strategically. Under the franchising model private bus operators would compete for contracts to run specified bus routes. The CPCA is currently reviewing whether to take up such bus franchising powers.

Regarding air quality, the Department for Environment, Food and Rural Affairs recently published its Clean Air Strategy 2019. However, as the Strategy admits, ‘*Local government has been the main agent for cleaning up local air since before the first Clean Air Act of 1956*’ (DEFRA, 2019a). Local air quality management is a statutory process that Cambridge City Council manage (Cambridge City Council, 2019a). The City Council monitor, assess and plan action to improve local air quality, in particular with regard to nitrogen dioxide and particulate matter (PM10 and PM2.5) (Cambridge City Council, 2019a). The most recent local air quality action plan for 2018-2023 was submitted by the Cambridge City Council and Cambridge County Council and sets out joint working between the City, the County and the Greater Cambridge Partnership (Cambridge City Council, 2018a). The latest action plan for 2018-2023 proposes the Cambridge city region improves air quality by tackling traffic emissions (Cambridge City Council, 2019b). The City Council is offering incentives for taxis to switch to less polluting vehicles - electric and petrol hybrid (Cambridge City Council, 2019b). The GCP is ‘actively considering’ a clean air zone for Cambridge which would restrict polluting vehicles’ access. Efforts to move buses and other heavy good vehicles to less polluting must be steered by the County Council, the GCP and the Combined Authority (Cambridge City Council, 2019b).

Currently, decentralised local energy generation does not make a significant contribution to energy supply in the Cambridge city region. The local energy distribution networks, operated by UK Power Networks, is structured to support one-way flow of energy, from production to consumers. Customers are in contractual relationship with supply companies that operate nationally. This fragmented and centralised governance structure represents a challenge in updating the physical grid to accommodate development and growth in housing and employment in the Cambridge city region. The recent regional collaboration among LEPs within the frames of the Greater South East Energy Hub

aims to address this issue. The Energy Hub has been set up to increase the number, quality and scale of local energy projects being delivered across the South East.

Efforts on improving telecommunications in the Cambridge region are spearheaded by Connecting Cambridgeshire. Connecting Cambridgeshire's digital connectivity programme includes '*improving mobile coverage, extending fibre networks to homes ... & businesses, expanding public access WiFi ..., [and] trialling 5G*' (next generation mobile) (Connecting Cambridgeshire, 2019). This vision is to be achieved through a combination of private sector and public funding. Connecting Cambridgeshire is supported by a £5.6m investment from the Combined Authority and £4m a funding for fibre upgrades from Central Government (Connecting Cambridgeshire, 2019). Connecting Cambridgeshire is led by Cambridgeshire County Council which works with other government institutions including Peterborough City Council and other local councils, the CPCA, the Government's Department for Digital, Culture, Media and Sport, as well as the private sector, namely telecoms suppliers (BT) and mobile operators (Connecting Cambridgeshire, 2019).

## 5 Discussion and Conclusions

The aim of this paper is to illustrate that a purely technology-driven approach to CDTs (and other modelling tools) is not likely to deliver on the promised benefits in terms of evidence-informed decision-making and better city-level policy and practical outcomes. Instead, CDTs (as next-generation urban modelling tools) need to contribute to transcending locally relevant organisational, institutional, and sectoral/systemic silos that hinder holistic responses to cross-cutting problems. The design and implementation of CDTs must therefore be challenge-driven (informed by locally relevant problems) and incorporate the views and requirements of multiple societal actors from various segments of the urban society. In the case of Cambridge, the challenges to be addressed are accommodating the projected population and employment growth while also tackling the interconnected problems of congestion and poor air quality. A systemic understanding of these problems highlighted the importance of decision-making processes carried out in several sectoral silos, including transport, energy, spatial planning (including land use and housing), air quality, and telecommunications.

The stakeholder mapping exercise presented in the previous section highlighted the following issues which need to be considered: first, the impact of fragmentation on the decisionmaking process and the capability to address cross-cutting issues; and second, their implications for evidence-informed decisionmaking.

Fragmentation across different levels of government (city/district, county, metropolitan, and up to national) leads to disconnect between strategic plans, and implementation and action 'on the ground'. Policies, strategies and interventions developed on different government levels are also underpinned by different evidence bases, produced often on a case-by-case basis by various consultants. This may result in underestimating the value of evidence in the decisionmaking process. Second, the typical silos between the public, market and third sector also contribute to a problems regarding the value of evidence (in this case, urban systems models). The modelling process is detached from its role in supporting decisions: decisionmakers often only see a ready-made interpretation of the results while data inputs, modelling assumptions and uncertainties are insufficiently understood. Moreover, only part of this information is open to scrutiny from the public, creating trust issues in the results and the decisions made based on these. Third, silos across vertically organised sectoral systems often lead to contradictory or incompatible decisions – each of which is underpinned by various (modelling) evidence locked into these sectoral silos.

In response to these issues, the requirements from local stakeholders for a Cambridge CDT prototype can be summarised as follows.

- It must be light-weight and user friendly enough to be used in-house to refine the options and questions to be explored through more detailed modelling which requires expert knowledge.
- The CDT needs to connect long-term strategic planning to short-term management and monitoring to support joint working across different government levels.
- It must contribute to connecting existing modelling efforts in different sectoral and systemic silos.

Moreover, if CDTs are to become integral parts of decision-making processes for city planning and management, the typical lack of transparency regarding both the assumptions built into them, as well as the associated uncertainties, must be addressed. This involves opening up the 'black box' of urban modelling towards stakeholders and citizens, and the democratisation of the modelling process. A more transparent use of evidence along the decisionmaking process (formation and use) and across various societal groups (including citizens) can contribute to improving the legitimacy of planning policies, strategies and interventions. This seems to be a pre-requisite for engaging and diverse conversations and debate over the possible options.

## Acknowledgements

The Authors would like to acknowledge the support received from Dr Jennifer Schooling, Dr Ajith Parlikad, Dr Ying Jin, Dr Noura Wahby and Mr Tianren Yang. Funding for this study has been provided by the Centre for Digital Built Britain, under InnovateUK grant number RG96233.

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