cdbb
Centre for Digital Built Britain

On the Governance of City Digital Twins

Insights from the Cambridge case study

Dr Timea Nochta, Nicole Badstuber and Dr Noura Wahby

July 2019
Series No: CDBB_WP_012
DOI: https://doi.org/10.17863/CAM.41083

UNIVERSITY OF CAMBRIDGE

Centre for Digital Built Britain

This is a working paper, published in the CDBB publication series. Prepared for "The governance of technology – Implications for the city-scale digital twin" project funded by the Centre for Digital Built Britain, under InnovateUK grant number RG96233.

Acknowledgements:

The authors would like to acknowledge the support received from Dr Jennifer Schooling, Dr Ajith Parlikad, Dr Li Wan and Tianren Yang.

This research was funded by the Centre for Digital Built Britain (CDBB). www.cdbb.cam.ac.uk

On the Governance of City Digital Twins – Insights from the Cambridge case study

Dr Timea Nochta, Nicole Badstuber and Dr Noura Wahby

Centre for Smart Infrastructure and Construction, Department of Engineering,
University of Cambridge

1 Introduction

1.1 Project objectives

The project investigates how currently existing governance systems (and their structural and cultural characteristics) influence what is considered feasible, appropriate and desirable in implementing digital solutions in cities. We use urban modelling, specifically the concept of city digital twins (CDTs), as a case study to analyse how multi-scale and multi-stakeholder decision-making environments, conditioned by distinct social contexts, impact city-wide technology development and deployment.

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. CDTs are *realistic* digital representations of physical city systems, assets and processes providing digital simulation and management environments to aid decision-making. Defining the concept of CDTs is still a work-in-progress (Bolton, Enzer and Schooling, 2018) – this process needs further refinement, input from a broader set of disciplines and critical thinking.

The project contributes to generating knowledge that is crucial to unlocking the potential of CDTs in delivering social, economic and environmental outcomes that meet citizens' needs and also respond to contemporary urban challenges. Such challenges include – but are not limited to – climate change mitigation and adaptation, urban sprawl, spatial inequality, air quality and strain on urban infrastructures and services. We contend that CDTs will not offer straightforward solutions to either of these. However, they provide a chance to look at challenges afresh, and to establish new governance structures and mechanisms which are better equipped to cope with or tackle them. CDTs therefore must be designed and implemented with an explicit aim of mitigating against structural failures in contemporary urban societies which produce (and re-produce) city challenges.

1.2 Background

The starting point for this investigation is that a complex relationship exists between societies and the technologies they invent, adopt and use, and the ways in which these processes unfold and influence development trajectories. Real-world outcomes are therefore understood as products of sociotechnical processes fuelled by feedback loops between the social and technological spheres allowing influence and information to travel in complex, non-linear ways in both directions. As a result, technology (including the digital) is never *neutral* or *objective.* Instead, the invention, adoption and use of specific technological solutions is influenced by the social world, in particular the existing

governance systems[1] relevant to (this) technology – the 'governance *of* technology'. At the same time, technology itself makes an impact on the social world as it becomes part of the governance structure and process – we term this 'governance *by* technology'.

Research into the links between society and digital technology often focuses specifically on algorithms as formalised descriptions of computational procedures, and investigates the societal implications of their operation. Algorithmic data processing represents a form of governance by technology: by performing *selection* and *ordering* of information it has the power to emphasise certain aspects of the sociotechnical assembly in which it operates while neglecting others. Thus, digital technology, in the form of algorithms and software more generally, is the starting point for these analyses. The aim here is to better understand technology's role in changing societies via automating (and commercialising) reality-mining and reality-construction (Saurwein, Just and Latzer, 2015; Just and Latzer, 2017). Re-defining 'what counts' as 'what we can compute' poses various risks including but not limited to manipulation, diminishing variety, constraints on the freedom of communication and expression, surveillance and threats to privacy, social discrimination, violation of intellectual property rights, abuse of market power, impact on cognitive capabilities and the brain, and growing heteronomy and loss of controllability (Saurwein, Just and Latzer, 2015).

In contrast, investigations into the 'governance of technology' (algorithms) depart from society and examine the influence of social structures and processes on the use of algorithms. This type of research often emphasises the need for developing knowledge about the "appropriate" governance structures and mechanisms to maximise the benefits and contain the risks of digital technology development and deployment. As the backbones of digital twins are systems-of-systems of "*digital control and management achieved through sensing, large-scale data storage and algorithmic processing*" (Dourish, 2016, p. 3), considering these issues must be central to the discourse around their design and implementation.

Understanding risks and their implications is necessary for developing knowledge about the options available to contain them. Such options may include for example state intervention (legislation and regulation), co-regulation (state and market), sectoral self-regulation (e.g. via professional standards), self-organisation (within companies), supply- and demand-side market solutions or a combination of some or all of these. Currently, it is still unclear how these options may apply for digital twins of buildings, assets, infrastructure systems or cities. To explore how CDTs could and should be designed and implemented *appropriately*, we propose to move away from the focus on the abstract process of *governing* and launch an enquiry into the societal *context*, both in terms of structure (patterns of relationships between actors and stakeholders) and culture (formal rules and regulations), as well as informal norms and logics of appropriateness (Barocas, Hood and Ziewitz, 2013; Kitchin, 2017). Assessing the impact of contextual characteristics on the design and implementation of digital twins for city planning (and management) is necessary to better understand the risks and challenges they might pose, as well as the tailored ways to incorporate CDTs in local governance.

1.3 The Cambridge Digital Twin case study

The specific challenges that the Cambridge City Digital Twin set out to address are tackling congestion and improving air quality in the Cambridge sub-region. A commitment exists locally to reduce car use

[1] *'Governance system'* here refers to structures and processes of social coordination arising from various decisions made by relevant (affected and/or interested) societal actors from the public and private sphere as well as the civil society. *'Governance'* appears as the outcome of the operation of governance systems.

by 24% by 2031 compared to 2011 baseline numbers while improving air quality and keeping pollutant concentrations (NO_2 and PM) within the safety limits set by national policy. These improvements will have to take place against a backdrop of 15% population growth from 2011 to 2031 and other economic and spatial development targets.

Besides the research output, "*The governance of technology – Implications for the city-scale digital twin*" project, together with inputs from the "Digital Cities for Change" project will deliver a governance framework to accompany the Cambridge Digital Twin. The Cambridge Digital Twin prototype is being delivered within the frames of the project entitled "*A City-Level Digital Twin Experiment for Exploring the Impacts of Digital Transformation on Journeys to Work in the Cambridge Sub-region*" (led by Dr Li Wan, Department of Land Economy, University of Cambridge).

The digital twin prototype articulates the historical trends of journeys to work in the Cambridge sub-region through urban system modelling and data analytics. The design of the new model incorporates insights from multiple disciplines to investigate how people of different age, socio-economic background and employment status travel to work, and how built-environment factors (e.g. dwelling density and workplace settings) may affect their travel and location choice. It explores the possible futures of journeys to work incorporating a series of socio-economic and technological development scenarios based on a number of policy variables including transport investments; housing/workplace developments (location, type, density); distribution of employment by full-/part-time and skill level; flexible working hours; and technology-enabled new working patterns (e.g. teleworking). The varying impacts of future development options will be visualised via a web-based modelling platform, aimed at fostering policy debates and public engagement.

The objectives set out for the Cambridge CDT governance framework include the mapping of relevant stakeholders and their relationships to each other across different scales of government and from the private sector to identify the key users of the digital twin and to incorporate their views and requirements in its design and implementation. Addressing the role of leadership is similarly important which involves developing knowledge about the appropriate governance structures and mechanisms to support the adoption, use and future development of the digital twin (including the financial aspect). On the practical level this means assigning the maintenance and future development of the twin to a specific organisation and identifying its responsibilities and links to other CDT users. Citizens will also be considered as a key stakeholder group. Finally, understanding the impact of local contextual characteristics on the CDT involves investigation into the co-factors that enable or constrain the local potential for data sharing, security, open data, transparency, accountability and local democracy.

2 Positioning the city digital twin as a next-generation urban modelling tool

Urban modelling through computer simulation has been used to inform policy and strategy for city planning since the 1950's. These modelling exercises tended to be sector-specific, aimed at simplifying urban processes and delivered by and to narrow circles of interested parties, researchers and users. The early pioneering work mainly focused on transport and land-use responding to challenges of "*transportation, congestion, decentralisation of activities in cities, and rising social and ethnic segregation, all set against to the need to renew our cities which were built rapidly and somewhat haphazardly in an earlier industrial era*" (Batty, forthcoming). Development efforts in the subsequent decades include modelling other urban infrastructures such as water and stormwater (Zoppou, 2001) or energy systems (Bahu *et al.*, 2013; Jennings, Fisk and Shah, 2014; Allegrini *et al.*, 2015); disaggregate

and dynamic agent-based simulations in addition to aggregative cross-sectional spatial interaction models (Huang *et al.*, 2014); and more sophisticated approaches to transport and land use modelling extending to supply-demand interactions, population and economic forecasts, and differentiating between various transport modes (Wegener, 2004). Early attempts as well as more recent urban models have consistently been criticised for example for the 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, among others (Batty, forthcoming). Despite the criticism, computerised models have made an impact on urban planning practice in many cities over the past decades.

The currently unfolding '4th Industrial Revolution' provides an opportunity to respond some of the criticisms and advance urban modelling tools: 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.

The ever-increasing computational capacity, and the spread of new technologies (e.g. increasing computing power, mobile sensing) and techniques (e.g. big data analytics, machine learning, BIM/CIM) act as drivers of change. While city-scale models have so far been predominantly used to support strategic planning decisions, these emerging technologies and techniques highlight the potential of integrating operational, short-term management and long-term strategic decision-making not only by increasing the accuracy of long-term predictions, but also offering a possibility for monitoring progress and auditing – verifying the impact of certain decisions for a potentially larger set of societal actors. This may lead to more effective participation in decision-making processes from citizens and citizen groups.

We argue that for CDTs to become part of a paradigm shift in urban modelling practice there is a need to look beyond these technological factors and incorporate a distinct societal aspect into their design and implementation. Taking a sociotechnical perspective early on in this process will increase the chances of exploiting this emerging solution for the benefit of citizens, allowing it to move beyond a mere hype technology.

In order to support meaningful change, progress in developing CDTs must be directed to acknowledge the implications and deal with *societies*. In particular, the following societal factors seem to be relevant:

- the impact of multi-level and multi-stakeholder governance systems in which they ought to function;
- the associated opportunities, limitations and risks with regard to data sharing and security;
- sectoral and professional silos to address cross-cutting urban problems;
- the typical lack of citizen engagement in urban modelling and analytics to increase the legitimacy of predictions;
- and the locally relevant co-factors that influence the potential to facilitate these changes in practice.

Arguably, there will also be a need for CDTs to continuously evolve over time to incorporate technological innovation as well as changing perceptions on the societal challenges to be solved. This in turn requires progress in terms of skills and competencies not only in the case of urban planners and managers, but also technology providers, third sector organisations and communities.

In the following we will explore the implications of the digital twin approach on the currently existing governance of urban modelling and analytics. This investigation involves three elements: governance process (modelling as use of evidence in planning decision-making; section 3), structure (actors and actor constellations involved in data generation, processing and the interpretation of results; section 4) and co-factors (contextual characteristics enabling or constricting data sharing, security, transparency, accountability and participation; section 5).

3 Perspectives on governance I: Use of evidence in decision-making for city planning and management

3.1 Insights from existing literature

The move from classical public administration towards the public management model in public policy-making, administration and service delivery from the 1970's has driven the development of a more *rational* process of decision-making informed by *evidence*. The use of evidence to support policy, implementation and service delivery has come to be seen as contributing to efficiency, effectiveness and improving the perceived legitimacy of policies and civic trust in decision-makers (Head, 2015). Evidence is derived from relevant scientific information to construct policy advice or evaluation through the use of various tools and instruments for data collection; problem framing and structuring; defining objectives; and providing options for assessment and recommendations (Turnpenny et al., 2015; Dunn, 2015). Tools and instruments are used for example to collect data (e.g. survey, sensors or statistics); to frame and structure the policy problem in question (e.g. mapping tools, expert reports, stakeholder workshops, opinion polls, decision theatres); to define objectives (e.g. scenario analyses); and to produce assessment and recommendations (e.g. cost-benefit analyses, economic forecasting, computerised models and simulations) (Nochta and Radcliffe, 2018).

Echenique (2019, forthcoming) argues that models, either in implicit or explicit forms, are and have always been part of the decision-making process in urban planning. Computerised models of cities fall into the 'explicit' category and can potentially contribute to making decision-making processes more objective and transparent by providing an evidence base that can be assessed critically by others. Although urban models have been designed and deployed in many cities to simulate the potential outcomes of planning policies and interventions since the dawn of computers, the impact and value of the ongoing digitalisation processes in many domains relevant to urban modelling and analytics remains unclear. There is a similar lack of clarity around the potential of urban models to influence decision-making: in many cases "*big decisions on cities' future plans and investments still rest, like they always have done, on intuition, instincts and inspiring anecdotes*" (derived from what Echenique categorised as 'implicit' models in decisionmakers' minds; Jin, forthcoming).

Considering urban modelling and analytics as part of the evidence base which informs planning decision-making points to some critical issues around the governance of the production of this evidence that may hinder its potential in contributing to the decision-making process. First, improving the planning process is becoming an increasingly *salient* issue in the contemporary era where many cities around the globe grapple with parallel challenges of growing population (and growing needs to be served), growing spatial inequality, economic stagnation and climate change mitigation and adaptation. This also requires the ability to connect long-term strategic planning to short-term management and operational decisions, transcending various temporal scales. Second, there is a clear opportunity to exploit the ongoing digital revolution to improve the *credibility* of model outputs as evidence for decisions by collecting more large-scale, localised, up-to-date, dynamic data and

deploying advanced methods of data processing and analysis. This involves connecting modelling efforts in various sectors to improve the accuracy of sectoral predictions. Thirdly, the *legitimacy* of modelling outputs can be enhanced by acknowledging the multi-actor decision-making environment that has an impact on urban planning, including both public and private sector stakeholders, users and technology providers, as well as citizens.

Thus, while technological advancement may contribute to building better models providing more accurate predictions, harnessing the benefits that this may offer necessitates the development of a more systemic, challenge-driven approach to modelling, as well as democratising the process in which results are produced, used and communicated in the decision-making process. This way, the next generation of urban modelling tools, such as city digital twins, may contribute to intermediation, boundary spanning and management across the multi-actor and multi-level organisational landscape (Carlile, 2004; Trompette and Vinck, 2009; White *et al.*, 2010).

3.2 Urban models and the use of evidence for planning in Cambridge

Modelling and analysis are used by local government in Cambridge to argue for funding and investment and to address concerns raised about the impact of new development. Modelling of transport and air quality is used by the transport, air quality and planning units to forecast the impact of interventions. Modelling and analysis of data is predominately outsourced to consultants by all levels of government. In the transport sector, this contractual arrangement dates back 25 years to when the decision was made to outsource modelling capability. This has made local government reliant on limited transport consultants for the provision of expertise and evidence. Across the different government institutions in Greater Cambridge, the County Council has the most modelling expertise. In the planning sector, transport consultants are also contracted to model the impact of developments on traffic by the Council's local planning teams and developers. For air quality, Cambridge City Council has a long-term contract with a university spin-off consultancy which produces their air quality modelling.

There are difficulties in sourcing accurate and useful data for forecast modelling. In the transport sector, the models are based on national level data including the census (now 8 years old as the last census was completed in 2011) and national travel survey data. Often this data is not accurate at a granular level. Some transport data is collected at the local level in Cambridge and Cambridgeshire, through traffic counts, cameras fitted with automatic number plate recognition technology and local travel surveys. Most recently the Greater Cambridge Partnership conducted a widely distributed travel survey (GCP, 2018a). However, when council employees compared the national survey data scaled to the local level for Cambridge and Cambridgeshire with locally collected travel data, they found it to be a poor match. National data often did not reflect observed 'on the ground' conditions. This suggests the nationally provided data and the analysis used to distil regional data were inaccurate. In planning, the results of commissioned transport modelling were also questioned. In addition to data accuracy, planners criticised that traffic modelling was predominately limited to motorised vehicle movements while not including public transport, cycling and walking. Traffic modelling in planning is used to understand the impact of new developments on the road network. Planners interviewed criticised the 'black or white' findings, which conclude the need to upgrade road infrastructure if traffic thresholds are met. This means that, in the extreme, one extra home, and one extra car in turn, might push the traffic volume across the threshold and may be used to argue the case for a necessary road upgrade. Air quality monitoring and modelling is a notoriously difficult task and often produces results with large margins of error. This makes it possible for the City Council to track the general direction of travel

but does not allow for accurate near-real-time data streams (which often dominates the discourse around digital twins).

The complexity of governance in Cambridge and Cambridgeshire has led to fragmentation of data and evidence. In addition, data ownership is further fragmented by private ownership, such as developers, air quality monitoring station owners and private bus and rail operators. Access to data is impeded by charges for accessing data levied by data owners, such as owners of air quality monitoring equipment, as well as data owners refusing to share data on competition grounds, such as bus and rail operators. Local government does not have the powers to request and receive this transport data from data owners. Interviewees called for better contracts which required data producers to share data, for example in exchange for using public authority data.

The complexity of governance in the city region has also led to the fragmentation of evidence gathering. Evidence commissioned from consultants is often not readily available or shared after gathered. This has led to local government commissioning reports on similar topics over multiple years. As well as the lack of institutional knowledge and knowledge sharing across these years, different government layers having overlapping responsibility for example in transport, leading to each government institutions commissioning their own work.

The reliance on contractors has been both criticised and applauded by interviewees. Limited specialised expertise in contract commissioning has led to a narrow scope of contracted terms of reference, and limited scope for evaluating submitted data. It also leads to similar work being contracting out of similar tasks every few years. There is frustration among local government on not being able to test different scenarios using the model and needing to contract or solicit minute details from contractors. Similarly, officers have expressed grievances on the assumptions that form the basis for these transport models, which leads to friction between what the transport model will recommend as an intervention and the policy priorities. For example, transport models currently estimate vehicular movements, but provide less data on cycling and none on pedestrian movements. This can lead to transport models recommending upgrades to roads because new developments along the route mean capacity thresholds are reached. However, this might undermine policy efforts to encourage mode shift or develop car-light new developments.

On the other hand, some interviewees praised the efficiency of contracting out services. It means that the staff are only being paid occasionally to work on projects, they argue. Interviewees added that it would be more costly for the organisation to pay for that capability in house and that transport consultancies could offer transport modellers more competitive remuneration packages than local government could. It was therefore seen as difficult and costly to attract modellers to work for local authorities. Nevertheless, the working relationship between local government and the transport modellers at consultancies is described as good. One interviewee referred to the consultants she works with as the county council or the GCP's modelling team. Consultants are available when requested and on hand to answer detailed questions on the models. One interviewee described the relationship as if they were one team, comparable to colleagues working in the same organisation. However, the policy decision to contract out transport modelling has resulted in the County Council being dependent on a few transport consultancies, which retrain crucial expertise and experience in running Cambridge's transport models.

3.3 Citizen engagement in the production of evidence in Cambridge

Citizen engagement is at the core of local decision-making processes. In Cambridge, different levels of government have developed different forms of public consultations to supply grounded evidence for policy-making. First, the city council runs consultation through city wide meetings, such as at the Annual Council meeting, or at local area committees where residents can voice their concerns on different local issues (Cambridge City Council, 2019a). In particular, specific consultations are convened for budget plans, comments on planning applications for new developments, and any issues the City council decides to open up to the public, such as the latest call for land release in the South Cambridgeshire district (Cambridge City Council, 2019b).

With the additional layers of governance added to the region's local decision-making entities, such as the Combined Authority (CA) and the Greater Cambridgeshire Partnership (GCP), new approaches to citizen inclusion have been added. The GCP itself was launched in July 2017 as a response to the opaque consultation of the 2014 City Deal signing, which citizen groups across Cambridge were campaigning for, and the new institution has since developed both its recruitment and outreach schemes. In particular, the GCP has since developed both a targeted and wider approach to tapping into residents' voices. In the case of the latter, shortly after its launch, the GCP opened the Big Conversation Survey on its website, which gathered over 10,000 responses on the future of the region (Cambridgeshire Insight, 2017a), as well as a 2017 Future transport research on Cambridge and South Cambridge (Cambridgeshire County Council, 2017), and the subsequent Greater Cambridge Travel Survey Report (GCP, 2018b). More recently, the GCP has carried out a public consultation on transport modal shifts through the Choices for Better consultation (March 2019). The GCP particularly promoted this initiative on social media, through information 'pop-ups' across the city and villages, as well as in local residents' meetings and has gathered over 5,000 responses (GCP, 2019a). Local residents' associations have also separately submitted responses to the consultation and have been active in land-use and planning issues in past years.

As for targeted consultation strategies, the GCP has also been active in bringing citizens' voices to the design of policies and local schemes. It has created an institutional form of consulting residents on specific projects through 'Local Liaison Forums' (LLF). These spaces have emerged as important for dialogue with residents on new development planning, infrastructure issues, transport, and overall city management. In the case of the of the 2018 Cambridge South East Transport Consultation, for example, following an online survey, the LLFs serve as a meeting place for further discussion on current issues around the A1307 between Haverhill and Cambridge (GCP, 2018c). These forums are chaired by local councillors and are usually run biannually. Their success remains a matter of debate, as in the case of the Milton Road development (Milton Road Residents Association, 2018). At the same time, the GCP has employed the use of public exhibitions to keep residents informed of projects' progress and emerging designs.

A third type of community consultation has proven to be a much fruitful approach to inclusive policy-making. In certain policy spheres, councillors and local mayors have played an important role in creating institutional access to citizen groups. These cases present a personalised vested interest of politicians to changing the nature of local decision-making by pluralising voices in shaping local visions. In the case of St. Neots, local freelancers and artists based in the town came together to form the 'Neotists' in order to simply find spaces for communal working, as well as an extended professional community network (Neotists, 2019). Soon, however, they became involved in local policy-making as local plans for the expansion of the market town plan were being debated in the public sphere, as well

as new developments as part of the City Deal (Combined Authority, 2018). The group was soon involved by their local councillors in several local events as a collective voice of the creative commons, such as the Cambridge County Council's Future Takeover event on smart growth in the region. More significantly, due to the district council's dedication to the inclusion of arts and culture in the wider vision for the town's development, the group is also involved in strategic planning committees and have recommended new local projects that impact city growth, such as planning developments and infrastructure across the city like cycle and foot paths. The importance of city spaces for leisure and environmental interests will thus be advocated by the group in the Combined Authority's master plan steering group, due to their empowerment by the district council (Combined Authority, 2018).

The involvement of Cambridgeshire residents in these consultations has provided public institutions with evidence of public opinion and citizens' voices on local issues. These collected voices however made a limited impact on changing proposed solutions and in some cases influencing policy options in issues like transport plans and choices for the sub-region.

4 Perspectives on governance II: Multi-level, multi-stakeholder decision-making

4.1 Insights from existing literature

Traditionally, the number of actors involved in urban modelling exercises has been relatively small compared to the number of actors involved in the planning decision-making process. The production of evidence, or the modelling process itself, is most often undertaken by external technology providers (consultants, researchers, etc.) and the assumptions contained in the modelling inputs and processing algorithms remain unclear to some of the decision-makers (users). The interpretation of the modelling results is often delivered to users in the form of a report with limited technical specifications on the modelling process included. Modelling exercises tend to be sector-specific and the modelling of different infrastructure systems in the same city are not integrated, often resulting in contradicting or confusing recommendations for planning policy and interventions. This is coupled with several layers of government having an impact, or in fact specific powers or responsibilities, on decisions made regarding urban infrastructures.

Fragmentation therefore appears along multiple dimensions in the multi-actor and multi-level decision-making environment in urban planning. These include vertical (across different levels of government), horizontal (between the public and private sector and civil society) and sectoral or systemic (e.g. transport, energy, housing, air quality, etc) divisions, as well as a lack of appropriate link between long-term strategic decisions, the management of urban infrastructures and delivering public (and private) services which depend on these infrastructures.

A systemic view on contemporary urban challenges however requires more integrated efforts: such challenges develop from structural (and processual) failures of urban governance systems in spaces which Hajer (2003) calls 'institutional voids'. In order to deal with such cross-cutting issues, a large body of public administration literature has been developed over the past decades around the concept of 'governance networks' which are seen as governance arrangements providing semi-institutionalised contexts for decision-making in such situations (Klijn and Koppenjan, 2015). The analysis of governance networks focuses on structure (actor and network mapping and analysis), process (the rules and roles emerging in a network context) as well as the understanding of the historical process of collaboration and network evolution (game analysis; Klijn and Koppenjan, 2015).

In the following sub-sections, we take a network perspective and present the actor constellations (actor and network analysis) relevant to urban planning in Cambridge, with an emphasis on urban modelling. This analysis is used to understand the governance context in which the Cambridge CDT will need to function in the future, and how it might act as an enabler of collaboration and intermediation across the fragmented decision-making arenas and processes that have an impact on urban planning in Cambridge.

4.2 Stakeholder mapping for urban modelling in Cambridge: roles & relationships

The governance arrangements for the Cambridge region are complex. Interviewees have described it as 'the most complex in the country'. There are three layers of local government (below the national) in the wider Cambridge city region: district, county, and regional/metropolitan. In addition, a delivery body focused on growth and transport in facilitating growth in the region was established. Following a funding arrangement with central government, the Greater Cambridge Partnership, was established in 2014. The locus of policy making sits at different government levels for the different policy domains of transport, energy, planning and air quality. Planning and air quality decisions are made at district level. Responsibility for transport is spread across different government layers and also in the private sector, but broadly, responsibility for roads lies at the County Council level, and public transport is provided by the private sector which is regulated by the Office for Roads and Rail. Bus services must be registered with the Traffic Commissioner for the East of England. There are also national actors that play a role, namely: rail infrastructure manager Network Rail, rail franchise decision maker is the Department for Transport and the highways agency reflected in Highways England. The energy sector is centralised and privatised. It is regulated by Ofgem on behalf of the Gas and Electricity Markets Authority (Rhodes et al., 2018). There are three different actor groups involved in connecting supplying energy to users: the generators, the network operators and the retailers (Energy Networks Association, 2019). The local energy distribution network in the East of England which covers Cambridge and Cambridgeshire is operated by UK Power Networks as a natural monopoly. The County Council have highlighted the need for investment in the energy infrastructure. Currently, the energy infrastructure is limiting development as the grid is at capacity. It is set up as a one-way system (from large-scale power generations distributed to the customers) which inhibits decentralisation and local production without infrastructure upgrades.

The city/district level is the most local level. Air quality and planning is the responsibility of the city/district councils, namely the Cambridge City Council and the South Cambridgeshire Council which envelopes Cambridge city. Planning in Cambridge is an example of how actors have attempted to overcome the jurisdictional fragmentation. Cambridge City Council and South Cambridgeshire have a function joint planning authority which collectively plans for development in the Cambridge and South Cambridgeshire. Cambridge has ambitious plans for growth. It is planning to add 14,000 new homes in the city by 2031. Housing development is led by the private sector in Cambridge as it is across England. However, the University of Cambridge is also playing a steering role in development in the region. The university if currently developing the housing and research facilities across two greenfield developments in Cambridge: at the North West and West Cambridge sites.

Air quality is a statutory process that the city/district council is responsible for (Cambridge City Council, 2019c). The City Council is responsible for a Air Quality Monitoring Area (AQMA) covering the city proper. South Cambridgeshire has a AQMA along the A11. Both are registered with central government. The council is responsible for producing a local air quality action plan. The most recent air quality action plan covers the period of 2018-2023. It was submitted jointly by the Cambridge City

Council and Cambridge County Council. It sets out a joint working relationship between the City, the County and the Greater Cambridge Partnership (Cambridge City Council, 2018a). The latest action plan for 2018-2023 points out how tackling traffic emissions is an imperative to improve air quality (Cambridge City Council, 2019b). Different government layer have powers to clean the vehicle fleet. The City Council is offering incentives to taxis to switch to less polluting vehicles, either electric and petrol hybrid (Cambridge City Council, 2019d). 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, 2019d). If the Combined Authority took up bus franchising powers, it could stipulate that only 'clean' buses could be used on bus routes. Alternatively, it could enter into a quality partnership agreement with existing bus operators which might set out requirements for bus emissions and the bus operator would be financially incentivised to clean their fleet.

The Greater Cambridge Partnership (GCP) has a commitment to promoting sustainable travel choices and supporting the development of a better public transport network. Following the signing of the City Deal funding agreement in 2014, Central Government provided the city region with money to invest in infrastructure to accelerate growth in the region. The GCP was established to manage the City deal commitments, and, its transport programme specifically supports the growth and developments set out by the Cambridge City Council. The city deal is worth up to £1bn over the 15 years the city deal will be in place (Greater Cambridgeshire Partnership, 2019a). The GCP have funded transport projects that promote sustainable travel such as cycleways, park and ride and bus priority (Greater Cambridgeshire Partnership, 2019b). It comprises of four partners: Cambridge City Council, South Cambridgeshire Council (South Cambridgeshire completely encircles Cambridge City), Cambridgeshire County Council and the University of Cambridge (Greater Cambridgeshire Partnership, 2019a). The GCP must work with government institutions, district council, county council and the combined authority to implement its projects.

In March 2017, central government added another layer of government to the region: the Cambridgeshire and Peterborough Combined Authority (CPCA). This government layer has responsibility for regional transport projects. The Mayor of the Combined Authority has commissioned transport consultants Steer to prepare the case for the development of an autonomous mass transit system for Cambridge city region, called Cambridge Autonomous Metro (CAM) (Steer, 2019). The strategic case for CAM was published earlier this year (Steer, 2019). The Combined Authority has the possibility of taking on other transport powers. The Bus Services Act 2017 gave newly devolved combined authorities with an elected mayor the right to apply to have bus franchising powers. This would allow the city region to run buses akin to the London model which would give the city region more control over the bus network and bus routes. Currently the bus sector outside of London is privatised and deregulated. This means private bus operators set where, when and how frequently to run bus services. Bus franchising would end the current privatised and deregulated bus sector and local government would regain strategic management and planning of the bus network. Local government would then contract bus services along routes from the private sector via competition for the market. However, the Combined Authority does not currently have these powers.

Policy decisions with regards to energy are highly centralised in the UK and mostly sit with the Department for Business, Energy and Industrial Strategy, and the regulator, Ofgem. Currently, decentralised local energy generation does not make a significant contribution to energy supply in the Cambridge city region. The local energy distribution network, operated by UK Power Networks, is

structured to support one-way flow of energy, from large power stations to customers. Customers are in contractual relationship with supply companies rather than the distribution network operator. This fragmented and centralised governance structure is a challenge for Cambridge and other local authorities in the country. The County Council and the Greater Cambridge Partnership only recently started working with other stakeholders (Local Enterprise Partnerships) on the local levels in the South East of England through the Greater South East Energy Hub. The Energy Hub has been set up to increase the number, quality and scale of local energy projects being delivered across the South East.

4.3 Citizens as stakeholders: Understanding the role and requirements of citizens in urban modelling and analysis

The role of citizens as stakeholders is a crucial node in local governance paradigms. Community groups in Cambridge have developed different strategies to influence policy and the various government layers based on local expertise and access to data. Two types of community groups are important in this regard. First, city-wide lobby groups, such as Smarter Cambridge Transport and CamCycle, have had some of the most success in influencing local policymakers. An important campaigning tool has been the use of data and policy analysis. Members lobby all layers of local government to gain access to surveys, urban models developed by private consultants, and public consultations carried out by councillors. This data has helped groups to articulate responses and provide alternatives to policy scenarios proposed by local councils, as well as highlight issues of data fragmentation, outdated data, and conflicting modelling outputs adopted by policy-makers.

A second group of engaged citizens are local residents' associations and activists. These associations focus on policy dialogue to influence decision-making on local schemes. Local bloggers have emerged as important sources of historical information on local democracy and development planning plans in Cambridgeshire, such as the videotaping of all community and council engagements (Carpen, 2019). Also, members engage directly with developers and big employers to influence local development plans and understand the projected growth. Similarly, members attend strategic planning meetings, such as the GCP general assembly meetings. They regularly table questions on the viability, assumptions, and integrity of modelling data used to create policy options for transport, air quality, environmental issues, and land-use planning, as some of the priorities for communities (Greater Cambridgeshire Partnership, 2019c). A gap has emerged in the limited interest of citizen groups in sectors such as energy and telecommunications, while residents recognise fragmented policies and the lack of holistic planning across transport and land-use for example.

Yet, several respondents professed limited abilities to analyse raw data, urban modelling and extract key implications from static equations. There is, however, great interest in harnessing the capabilities of these data privileges to provide evidence for decision-making. For example, in recent community forums with key figures in local government, community questions involved interrogations about government use of urban and economic modelling for land use, projected transport figures, and how future transport plans take into consideration affordability, special needs, and environmental factors. Similarly, engaged residents have an in-depth understanding of flawed experiments in local data collection. For example, several respondents brought up gaps in data collection for the GCP's Trip Chain Reports that were based on the 2017 Automatic Number Plate Recognition (ANPR) camera traffic surveys (Cambridgeshire Insight, 2017b). They indicated the missing number of cameras, random allocation of camera positions, and the skewed projections based on this data. Their inclusion in the initial design of data collection in their respective areas would have increased the integrity and reliability of the data in this case.

Similarly, residents have tabled requests to increase data collection methods in areas of potential economic growth. For instance, in the Histon Road and Milton Road area, members of the Histon Road residents' association have called for an increase in air quality monitors on their road. Residents requested monitors to be placed at different locations and timings of the construction phases of the Milton Road area in order to compare air quality levels during construction processes. In addition, residents called for widening the scope of these monitors to include Histon Road, rather than simply focusing on the more affluent Milton Road area, and to trace the wider impact of air quality levels (Greater Cambridgeshire Partnership, 2019c). These residents also insisted that this data should be "displayed and made easily available to the public", which demonstrates a grassroots recognition of the importance of data collection and the potential impact of these data sets.

As such, citizens groups have been active in campaigning for local issues and lobbying for greater inclusion in decision-making in the Cambridgeshire region. Their reliance on data and models is set to increase especially as they make their case for to prioritise local effects emerging from future large developments and economic growth.

5 Co-factors

5.1 Insights from existing literature

Local contextual conditions influence the way evidence is used in decision-making, as well the involvement of actors at different stages in this process. These may include written and formal rules (e.g. GDPR and other legislation and regulation of data sharing and use) but also unwritten informal social norms (e.g. previous experience of collaboration among stakeholders with access to different data sources; commercial interests, privacy concerns). These locally relevant factors are crucial to understand how the big data repositories and architectures that provide the backbone of moving towards a digital twin approach in urban modelling might be developed and maintained. Looking at the flow of data and information in more detail, there is a need to investigate where required data can be obtained and which stakeholders own or have access to these sources; how is it shared and used and by whom, both within and among local authorities as well as in the private sector; and provide opportunities for auditing and scrutiny.

From a data security perspective, the challenge-driven approach to developing CDTs must involve the creation of guidelines for data collection and sharing in an effort to minimise the potential of misuse. There appears to be an urgent need to develop a better understanding of what is the *sufficient* amount of information required to support urban planning, including implications for data collection. This may lead to a more proactive approach locally in relation to the types of data that can be collected and those that cannot, both by the public sector as well as private sector actors in order to address privacy and security concerns.

Ubiquitous data for urban modelling is often collected on and of citizens who are mostly unaware of the data collection taking place. Key governance questions to investigate therefore must include issues of privacy (transparency in the process of data collection on citizens), accountability and liability (transparency in terms of use of data and purposes) and participation (opportunities for CDT to support citizen involvement and consultation). The following sections present the currently dominant views and conditions in Cambridge relating to these co-factors that influence what governance structures and mechanisms could be employed locally to support the development and deployment of the Cambridge CDT.

5.2 Possibilities and barriers for data sharing among stakeholders to support the evolution of the Cambridge city digital twin

Two key obstacles to supporting the development of a Cambridge city digital twin are first, the pluralised private sector data owners and second, the lack of data sharing frameworks in place which would force the release of crucial data. Specific private sector data owners mentioned were, with regards to planning: developers and property owners; in the transport sector: the private bus and rail operators, as well as the Cambridge sub-regional transport model owned by a transport consultancy and ANPR (automatic number plate recognition) camera owners (used to traffic monitoring); with regards to air quality: the owners of monitoring equipment.

Interviewees felt that with better contracts or data sharing agreements that required private sector data owners to share data in return (reciprocity) this could be addressed. Multiple data owners increase the number of interfaces that local government must engage with and this in turns requires time and capacity for local government to collate the data. In many instances, local government has been required to pay to access data: for example, local government needs to pay to the owners of air quality monitoring equipment to access air quality data. Around five years ago, a private-public partnership model was adopted for management of the street lights. This was before the integral nature of street lighting to power sensors gained salience in local government. Now local government will need to pay to install or access any new sensing equipment on street lighting, as this 'rental scheme' forms the income stream for the private company holding the management contract.

The Cambridge city region already has some online tools available that showcase some of the characteristics one might expect from a city region digital twin: a data repository and real time transport data feeds. The former is Cambridgeshire Insight, a group hosted at the Cambridgeshire County Council. It exists to satisfy the data transparency requirements of the council but also to make the data more accessible for the public. It focuses on data visualisations to show case the data available as well as its use. The second is Smart Cambridge which hosts 'live' (with only short delays) data feeds of transport services across Cambridge.

The expectation from interviewees is that a Cambridge city digital twin would bring the data library and real time data function together in one tool and that this tool would also allow local government to explore different scenarios through quick modelling of forecasts given different parameters. Interviewees felt that accessibility and easy usability were key for it to be useful for local government. Descriptions of what a Cambridge city digital twin might be suggest an easily navigable dashboard with long-term modelling capability. This ideal Cambridge city digital twin would also bring together data from different policy silos. Any modelling or forecasting that the digital twin would do should illustrate the interdependence between policy areas.

5.3 Citizens' perspectives on using data and modelling for planning policy making in Cambridge

As citizens become more involved in local politics and call for improved policy-making, the use of data for evidence will be essential in the 2019 cycle of local plans as well as associated ethical and privacy concerns. This section describes how citizen groups envision the impact of data collection on principles of transparency, democracy and participation at the local level.

Government institutions have been vigilant in their adherence to high standards of data privacy, such as in collecting and anonymising data for the Cambridge Sub Regional Model (CSRM) (WSP Group and Atkins, 2015). However, several research respondents remain unconcerned about data privacy issues.

They indicate “we are already being watched” and believe that these data collection strategies, such as counting traffic, census data, and air quality monitors among others, are vital for better policy-making. Residents believed that data was already being collected through navigation systems, and planning applications submitted for new developments. In fact, many insisted that the need for updated data in the Cambridge area was vital, and that the newer data applications developed by Smart Cambridge for example, were very effective (Smart Cambridge, 2019). In fact, groups like the Cambridge Bus Users group indicate as part of their lobbying strategy the need to implement the Bus Open Data principles enshrined in the Bus Services Act (2017) with local operators. The need for real time information and open access data remains a more pressing issue for these groups than privacy concerns (CABU, 2018).

In addition, limited access to data has spurred different types of community action that have affected local democratic process and opened paths for participation. For instance, in the case of bus franchising, a fierce debate has erupted in Cambridge’s policy circles and among bus activists on the advantages and disadvantages of this policy option for better bus services (CABU, 2019). This debate even brought bus operators to publicly express their visions for better services, including the operators Stagecoach (Campbell, 2018), and Whippet (Hamilton, 2018). Thus, data offers the opportunity for principles of participation to be realistically implemented in multi-stakeholder policy dialogues. Similarly, if the Combined Authority opted for bus franchising powers, the scope for more ownership over bus data would be beneficial for bus users and improving services through increased transparency and spaces for participatory planning.

The use of social media by different community activists has also been used to hold local councillors to account. Twitter threads have become a powerful tool, for example, to incite explanations from politicians and organisations on local plans and data discrepancies. The ongoing case of Montreal Square for example, highlights how residents continue to contest resettlement schemes and developers’ plans in high value land in Cambridge city. Although in this case, a non-profit housing association is interested in increasing affordable housing in the area, residents’ attachment to their communities and demand for methodological needs assessment have been vocalised and residents continue to protest the ongoing planning phase. These sporadic developer schemes across the city prioritise densification and the demand for housing, but they have not found a solution for cooperative dialogue with residents and strategies to limit disruption to the local community fabric.

This ‘virtual’ public sphere of conflicting data thus provides direct community and individual involvement in local democracy. Yet, these multiple sources of data stagger the level of inclusion in direct policy-making and limit transparent flows of information to citizens. In some cases, these multiple processes have resulted in conflicting policy options and the prioritisation of political decisions.

6 Early findings and future research agenda

This report aimed at providing an overview of the emerging research findings and streams of interest using a case study of the governance of urban modelling, and the changes required to move towards a CDT approach in the Cambridge city region. Our preliminary research findings have addressed three main themes that require further investigation, and provide initial input to developing a research framework and methodology (see section 9 Appendix) which will be refined further through more detailed investigation into the Cambridge case and via comparing this to other city cases.

First, structural issues in the governance of urban analytics are crucial to understanding flows of decision-making across government levels. Cambridge presented a unique case of multiple state layers that has resulted in a more complex process of policy-making, coupled with the hollowing out of local government. As more layers of regional government are added, expertise and skills are dispersed across institutions leading to a deficit of expertise in different institutions, which has resulted on the reliance of a narrow pool of external consultants. Citizens have also voiced frustration at the difficulty of engaging with different government layers, whilst new forums for public consultation have created spaces for localised community conversations, such as the Local Liaison Forums spearheaded by the Greater Cambridgeshire Partnership (GCP). The proliferation of city-wide lobby groups and localised residents' associations have developed a strong third sector that contributes to emerging spaces of multi-stakeholder decision-making.

Second, the use of evidence for policy-making as a process is confronted with the fragmentation of policies across sectors and government layers. On the one hand, policy powers are dispersed amongst isolated silos that may have overlapping functions and result in a disjointed holistic policy approach to sectors such as transport, planning and land use, among others. On the other, fragmentation also occurs between public and private sectors, and has a direct implication on data collection, ownership and evidence commissioning. While at different layers of government, path dependency on legacy decisions remains, such as outsourcing strategic urban modelling, new institutional transformations are emerging to bring together related functions, such as the newly formed joint planning department for Cambridge city and the South Cambridgeshire district. Similarly, citizen groups are invested in harnessing the power for evidence to lobby for city solutions affecting their communities. Although limited public abilities to analyse data were expressed, engaged citizens recognised the significance of sound data collection, data reliability and integrity in order to produce better local policies based on current evidence.

Third, the case study provides evidence that local decision-making is conditioned by sets of formal and informal factors affecting data use and its translation into policy. On the one hand, access to data and transparency within government circles has been conditioned by structural constraints, such as data ownership limitations and data collection rental schemes. On the other hand, citizens have been calling for increased data access, which initiatives like Smart Cambridge have been active in addressing. Whilst government prioritises data security as part of privacy standards, citizens are more concerned with the need for improved data collection through real time data, rather than issues of security. Virtual data remains an important source of information for lobby groups, and visualisations provided by programmes such as Cambridgeshire Insight have proven significant for community groups and the private sector to build and mobilise responses for engagement in policy-making.

Based on these preliminary conclusions, the Cambridge case study provides insights on an important line of inquiry into the governance of urban analytics in a growing city. While smart solutions like city digital twins may contribute to improved evidence-informed decision-making, contextual factors will ultimately have a significant impact on the success of such digital tools by constraining and enabling the emergence and functioning of particular governance structures and processes on the local level. As such, a more detailed understanding of how the design, implementation and operation of digital twins can incorporate spaces of agency and transparency will provide improved strategic policy-making in places like Cambridge and elsewhere. The development of a transferable research framework and methodology which can guide inquiry into the context-specific implications of existing governance systems on the design, implementation and operation of digital tools (city digital twins)

for city planning and management can help address this point. Developing this framework and methodology is the main goal of this project – an early, outline version of this has been included in section 7 (Appendix).

7 Appendix: Research Framework

The preliminary results presented here contributed to the development of a research framework and methodology - which will require further refinement and testing in other city cases. The framework will also be used to systematically code all the collected secondary and primary data from the Cambridge case study. This framework will be tested against further city cases where city digital twin prototypes have been or are currently being developed, as well as iteratively improved based on new parameters.

RESEARCH FRAMEWORK	**Stakeholders & Users**	**Citizen Engagement**
Governance structure	• Current and future actor constellations • Stakeholder roles & changes • User requirements & interaction with CDTs • Skills requirements	• Citizens as stakeholders • Citizen groups' role in the multi-stakeholder environment • User requirements – possible & required interaction between citizens and the CDT
Improved use of evidence (process)	• Creating useful & usable information • Addressing cross-cutting issues: • Vertical (diff. govt levels) • Horizontal (across sectors of economy; between public and private spheres) • Intermediation – users & tech providers	• Involvement of citizens in the production of evidence (consultation processes) • Required frequency / form of collecting data from citizens to ensure a sociotechnical approach • CDT: understanding travel behaviour and potential for behaviour change; additional conditions for the changes to take effect;
Co-factors	• Data accessibility & ownership • Data sharing possibilities & barriers - data trusts • Data security	• Transparency as privacy: data collection on citizens • Accountability & liability: transparency in terms of use of data and purposes • Participation: opportunities for CDT to support citizen involvement and consultation

Table 1. Preliminary research framework – the governance of urban modelling and city digital twins

8 Appendix: Notes on methods of data collection

This research has employed a mixed methods approach to qualitative data collection in order to gain insights using multiple tools of enquiry. First, we have carried out 18 in-depth interviews with relevant stakeholders including government officers, political figures, urban modellers, residents' associations, and city-wide campaigning groups. Second, we have also used participant observation tools by attending community forums to understand residents' views and public consultation strategies. Third, we undertook desk-based research on local decision-making such as national and local policy documents, technical modelling reports, and academic papers on urban analytics, city planning and digital twins. Fourth, web scoping research has been conducted on community engagement schemes, social media platforms, alternative forms of work spaces, and historical transport schemes in the city. This data has been used in developing actor and network mapping, local narratives of engagement, and insights on the local policy-making process.

9 References

Allegrini, J. et al. (2015) 'A review of modelling approaches and tools for the simulation of district-scale energy systems', *Renewable and Sustainable Energy Reviews*. Pergamon, 52, pp. 1391–1404. doi: 10.1016/j.rser.2015.07.123.

Bahu, J. M. et al. (2013) 'Towards a 3D spatial urban energy modelling approach', in *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, pp. 33–41. doi: 10.5194/isprsannals-II-2-W1-33-2013.

Barocas, S., Hood, S. and Ziewitz, M. (2013) 'Governing Algorithms: A Provocation Piece', in *Governing Algorithms Conference*. New York, New York, USA, pp. 1–12. doi: 10.2139/ssrn.2245322.

Batty, M. (forthcoming). Generations of the Urban Model: History, Theory, Empiricism, and Applications. In *British Academy Proceedings on Applied Urban Modelling*. Oxford University Press.

Bolton, A., Enzer, M. and Schooling, J. (2018) The Gemini Principles. doi: 10.17863/CAM.32260.

CABU (2018) Passenger Information Displays/App – The Mystery of the Disappearing Buses. Available at: https://cbgbusers.wordpress.com/passenger-information-displays/#BusOpenDatahttps://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/722576/bus-open-data-case-for-change.pdf (Accessed: 18 April 2019).

CABU (2019) Bus Franchising, Quality Partnerships, and other ways of improving bus services. Available at: https://cbgbusers.wordpress.com/bus-franchising/ (Accessed: 18 April 2019).

Cambridge City Council. 2018a. Cambridge City Council: Air Quality Action Plan 2018-2023. Available at https://www.cambridge.gov.uk/media/3451/air-quality-action-plan-2018.pdf (Accessed 12 May 2019)

Cambridge City Council. 2018b. Cambridge Local Plan. Available at https://www.cambridge.gov.uk/urban-growth (Accessed 12 May 2019).

Cambridge City Council (2019a) Consultations | Cambridge City Council. Available at: https://www.cambridge.gov.uk/Consultations (Accessed: 18 April 2019).

Cambridge City Council (2019b) Greater Cambridge Local Plan: Call for sites consultation | Cambridge City Council. Available at: https://www.cambridge.gov.uk/consultations/greater-cambridge-local-plan-call-for-sites-consultation (Accessed: 18 April 2019).

Cambridge City Council. 2019c. Air pollution levels and monitoring them. Available at https://www.cambridge.gov.uk/air-pollution-levels-and-monitoring-them (Accessed 12 May 2019).

Cambridge City Council. 2019d. Improving air quality. Available at https://www.cambridge.gov.uk/improving-air-quality (Accessed 12 May 2019)

Cambridge City Council. 2019e. Urban growth. Available at https://www.cambridge.gov.uk/urban-growth (Accessed 12 May 2019)

Cambridge City Council. 2019f. Why is Cambridge growing. Accessed 12 May 2019. Available at https://www.cambridge.gov.uk/why-cambridge-is-growing

Cambridgeshire County Council (2017) Future Transport Research- Cambridge and South Cambridgeshire Residents' Survey. Cambridge. Available at: https://citydeal-live.storage.googleapis.com/upload/www.greatercambridge.org.uk/about-city-deal/Systra - Cambridgeshire Travel Survey Final Report.pdf (Accessed: 18 April 2019).

Cambridgeshire Insight (2017a) Data Story Series: On the Buses, GCP Our Big Conversation Survey Data: Part Two | Cambridgeshire Insight Open Data. Available at: https://data.cambridgeshireinsight.org.uk/story/data-story-series-buses-gcp-our-big-conversation-survey-data-part-two (Accessed: 18 April 2019).

Cambridgeshire Insight (2017b) Greater Cambridge ANPR Data: Trip Chain Reports | Cambridgeshire Insight Open Data. Available at: https://data.cambridgeshireinsight.org.uk/dataset/greater-cambridge-anpr-data-trip-chain-reports (Accessed: 18 April 2019).

Campbell, A. (2018) 'Franchise the buses? You need money in the tank', *Cambridge Independent*, 2 June. Available at: https://www.cambridgeindependent.co.uk/news/franchise-the-buses-you-need-money-in-the-tank-9052043/ (Accessed: 18 April 2019).

Carlile, P. R. (2004) 'Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries', *Organization Science*, 15(5), pp. 555–568. doi: 10.1287/orsc.1040.0094.

Carpen, A. (2019) A dragon's best friend. Available at: https://adragonsbestfriend.wordpress.com/ (Accessed: 18 April 2019).

Combined Authority. (2019) St Neots Masterplan for Growth: Strategic Business Case Phase One. Available at: http://cambridgeshirepeterborough-ca.gov.uk/assets/Combined-Authority/St-Neots-Masterplan-for-Growth-Phase-1-SBC.pdf (Accessed: 18 April 2019).

Dourish, P. (2016) 'Algorithms and their others: Algorithmic culture in context', *Big Data & Society*. SAGE Publications, UK: London, England, 3(2), p. 205395171666512. doi: 10.1177/2053951716665128.

Echenique, E. (forthcoming). Modelling for planning and transport policy. In *British Academy Proceedings on Applied Urban Modelling.* Oxford University Press.

Greater Cambridge Partnership. (2018a) Travel Survey Report. Available at https://www.greatercambridge.org.uk/download/7174/GCP%20Travel%20Survey_Final%20Report_April%202018.pdf?type=inline (Accessed 15 May 2019)

Greater Cambridge Partnership. (2018b) The Greater Cambridge Travel Survey – Prepared for the GCP. Cambridge. Available at: https://citydeal-live.storage.googleapis.com/upload/www.greatercambridge.org.uk/about-city-deal/GCP Travel Survey_Final Report_April 2018.pdf (Accessed: 18 April 2019).

Greater Cambridge Partnership. (2018c) Cambridge South East Transport Study background information. Available at: https://www.greatercambridge.org.uk/transport/transport-projects/cambridge_south_east_study/cambridge_south_east_study-background/ (Accessed: 18 April 2019).

Greater Cambridge Partnership. (2019a) Choices for Better Journeys. Available at: https://www.greatercambridge.org.uk/choices-for-better-journeys/ (Accessed: 18 April 2019).

Greater Cambridgeshire Partnership. (2019b) Transport Projects. Available at: https://www.greatercambridge.org.uk/transport/transport-projects/ (Accessed 18 April 2019)

Greater Cambridge Partnership. (2019c) Public Questions and Responses GCP Executive Board meeting 20 March 2019. Accessed on: http://scambs.moderngov.co.uk/documents/b50006780/Public%20Questions%20and%20Answers%20GCP%20Executive%20Board%2020%20March%202019%20Wednesday%2020-Mar-2019%2016.00%20Greate.pdf?T=9 (Accessed: 18 April 2019).

Hamilton, C. (2018) Response to Article on Bus Franchising from Stagecoach East. Cambridge. Available at: https://cbgbususers.files.wordpress.com/2018/09/response-to-stagecoach-article-v1-0-13-07-18.pdf (Accessed: 18 April 2019).

Hajer, M. (2003) 'Policy without Polity ? Policy Analysis and the Institutional Void', *Policy Sciences,* 36(2), pp. 175–195. doi: 10.1023/A:1024834510939.

Head, B. W. (2015) 'Toward More "Evidence-Informed" Policy Making?', *Public Administration Review*. John Wiley & Sons, Ltd (10.1111), pp. 472–484. doi: 10.1111/puar.12475.

Huang, Q. et al. (2014) 'A review of urban residential choice models using agent-based modeling', *Environ. Plann. B Plann. Des*. SAGE Publications, UK: London, England, 41(4), pp. 661–689. doi: 10.1068/b120043p.

Jennings, M., Fisk, D. and Shah, N. (2014) 'Modelling and optimization of retrofitting residential energy systems at the urban scale', *Energy.* Pergamon, 64, pp. 220–233. doi: 10.1016/j.energy.2013.10.076.

Jin, Y. (forthcoming). Introduction. In *British Academy Proceedings on Applied Urban Modelling*. Oxford University Press.

Just, N. and Latzer, M. (2017) 'Governance by algorithms: reality construction by algorithmic selection on the Internet', *Media, Culture and Society,* 39(2), pp. 238–258. doi: 10.1177/0163443716643157.

Kitchin, R. (2017) 'Thinking critically about and researching algorithms', *Information, Communication & Society.* Routledge, 20(1), pp. 14–29. doi: 10.1080/1369118X.2016.1154087.

Klijn, H. E. and Koppenjan, J. (2015) *Governance networks in the public sector.* Routledge. doi: 10.1016/B978-012673031-9/50018-6.

Milton Road Residents Association. (2018) Notes from the Milton LLF October 2018. Available at: https://www.miltonroadra.org/news/categories/city-deal (Accessed: 18 April 2019).

Neotists. (2019) Creative freelancers in St Neots and Cambridgeshire. Available at: https://www.neotists.co.uk/ (Accessed: 18 April 2019).

Nochta, T. and Radcliffe, J. (2018) *Across SCales in ENergy Decision-making (ASCEND) Literature Review.* Available at: https://www.birmingham.ac.uk/Documents/college-eps/energy/research/ascend/ascend-literature-review-final.pdf (Accessed: 23 April 2019).

Saurwein, F., Just, N. and Latzer, M. (2015) 'Governance of algorithms: options and limitations', *info.* Emerald Group Publishing Limited , 17(6), pp. 35–49. doi: 10.1108/info-05-2015-0025.

Smart Cambridge. (2019) MotionMap Travel App FAQs. Available at: https://www.connectingcambridgeshire.co.uk/smart-places/smart-cambridge/faqs/?utm_source=Twitter&utm_medium=social&utm_campaign=SocialSignIn&utm_content=MotionMap (Accessed: 18 April 2019).

Steer. (2019) Cambridgeshire Autonomous Metro Strategic Outline Business Case. Accessed on 15 May 2019. Available at cambridgeshirepeterborough-ca.gov.uk/assets/Uploads/CAM-SOBC-v2.1.pdf

Trompette, P. and Vinck, D. (2009) 'Revisiting the Notion of Boundary Object', *Revue d'anthropologie des connaissances*, 3(11), pp. 3–25. doi: 10.3917/rac.006.0003.

Wegener, M. (2004) 'Overview of Land-use Transport Models', in Hensher, D. A. and Button, K. (eds) *Transport Geography and Spatial Systems.* Kidlington, UK: Pergamon/Elsevier Science, pp. 127–146. Available at: http://www.spatialcomplexity.info/files/2013/11/MW_Handbook_in_Transport.pdf (Accessed: 8 April 2019).

White, D. D. et al. (2010) 'Credibility, salience, and legitimacy of boundary objects: Water managers' assessment of a simulation model in an immersive decision theater', *Science and Public Policy*. Oxford University Press, 37(3), pp. 219–232. doi: 10.3152/030234210X497726.

WSP Group and Atkins (2015) CSRM Modelling Summary Report for Cambridge and South Cambridgeshire Local Plans. Cambridge. Available at: https://www.cambridge.gov.uk/sites/www.cambridge.gov.uk/files/documents/M7 supplement - (Accessed: 18 April 2019).

Zoppou, C. (2001) 'Review of urban storm water models', *Environmental Modelling and Software.* Elsevier, pp. 195–231. doi: 10.1016/S1364-8152(00)00084-0.