Cover sheet

2018/19 ECR Project

The local governance of digital technology – Implications for the city-scale digital twin

Final Reporting

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Abstract

The project set out to examine how governance structures, processes and socio-political systems affect the adoption of new (digital) technologies – e.g. City Digital Twins – that provide evidence for policy making and implementation in urban planning and the management of urban infrastructures. Situating City Digital Twins as next-generation urban models, we analysed the existing practice of using computerised models to support decision-making in the multi-actor governance context of the Cambridge city region in the United Kingdom. The study traced modelling practices and evidence informed decision-making processes across a variety of sectors: transport, energy, land-use planning and telecommunications. Outcomes include the mapping of governance stakeholders in the wider Cambridge area, and the analysis of network relationships, to develop recommendations for the design and implementation of a Cambridge City Digital Twin. The role of citizens in the production of evidence was also examined with a participatory research approach to analysing citizen engagement initiatives and the impact of digital tools on democracy, participation and transparency in the local context. The results of the Cambridge case study are contrasted with international practice and global experiences pertinent to City Digital Twins in British, European and international cities. This comparative perspective provides initial insights to understand generalisation possibilities from the Cambridge case study.

Main Text

1. Introduction and project objectives

Cities around the world are facing pressing challenges including but not limited to growing populations (and growing needs to be served), urban sprawl, increasing spatial inequality, economic stagnation and the need to act on climate change (mitigation and adaptation). Addressing such city-level problems requires improved coordination, integration and interoperability across traditional silos in city planning, management and services. However, contemporary urban governance systems are often inadequate to deal with challenges that cut across traditional social, organisational, sectoral-systemic and other silos. In many cities, urban modelling exercises have been used for decades to provide evidence for different decision-making processes in urban planning and management. However, these are seldom linked together into a coherent and comprehensive evidence base that cuts across silos and contributes to responding cross-cutting issues.

Against this backdrop, 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 the next generation of urban models, and analyse how multi-scale and multi-stakeholder decision-making environments, conditioned by distinct social contexts, impact city-wide technology development and deployment. We thus see the role of city digital twins in addressing this issue by providing a framework, involving technical as well as social elements, for linking decision-making processes and evidence bases pertinent to pressing cross-cutting problems.

Using the case study of the Cambridge city region (United Kingdom), this project adopts a three-pronged approach to examining the emerging concept of use of City Digital Twins (CDTs) as a new form of urban analytics, and its impact on the process of evidence production for policy-making. The first objective was to undertake a focused literature review of the use of the Digital Twin technology in cities, and associated governance implications based on empirical research carried out in global contexts. Second, the project analysed the governance processes and structures around a City Digital Twin prototype for the city of Cambridge in the UK. This component focused on local stakeholders such as local and regional governments and the private sector; yet, the third sector emerged as a

dominant force in the local context. As such, the objectives of the project expanded to provide an analysis of citizen engagement practices and the role of participation in the policy-making process as part of the evidence-base used by planners and elected decision-makers alongside modelling results and other information. Finally, the project aimed to develop a comparative study of international experiences of City Digital Twins globally to construct cross-country parameters to assessing how the concept of CDTs is understood and adopted locally in diverse urban settings.

This report details the overall research design of the project and the results from the three project axes. Section 2 provides an overview of academic literature focused on the use of City Digital Twins as a new approach to urban modelling and evidence for policy-making. Section 3 expands on the adopted research design and methodological tools for the project. Section 4 examines the results of the project from the governance and citizen engagement perspectives, as well as the themes emerging from the comparative study. Finally, the 'Conclusions' section discusses the recommendations for City Digital Twins and the implications of a governance lens on the adoption of digital tools for city management.

2. Insights from literature review

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. CDTS, if they are to move beyond mere hype technology and become the next generation of urban models, 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. It is thus necessary to consider a broader set of requirements compared to the mainstream discourse for the design and implementation of CDTs.

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, strain on resources, infrastructures and the services that depend on these, increasing spatial inequality, economic stagnation and so on. 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, marker 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 highlights an additional, third form of fragmentation. This work sees cities as complex systems of systems (Rogers, 2018; e.g. infrastructures such as transport, energy, water; and services including healthcare, social care, education, etc) which 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.

The above discussion highlights the potential of conceptualising city digital twins (as next-generation urban models) developing organically as federated systems-of-systems that serve as simulation and management environments and provide the currently missing links between existing specialised urban models. The ways in which such models get linked to each other must be informed by pressing local challenges for urban planning and management. In turn, city digital twins and the links they highlight may shed light on previously overlooked system interdependencies and can potentially contribute to negotiating responsibilities and accountability relationships across the governance landscape. By doing so, they can contribute to developing more holistic responses to cross-cutting urban problems.

3. Research design and methods

3.1 Research design

The research project involves two components: the case study of the development of a CDT prototype for the Cambridge city region, and a comparative study aimed at understanding the opportunities and limitations for generalising insights from the case study.

For the case study, the research team has established a working relationship with various local government bodies, including the Cambridge County Council's Smart Cambridge team. In collaboration with Smart Cambridge, a stakeholder workshop was organised in December 2018 involving representatives from the Cambridge City Council, Cambridge County Council, the Greater Cambridge Partnership (GCP) and the Cambridge and Peterborough Combined Authority (CPCA). The aim of the workshop was to determine priority areas for policy and action in which a city digital twin could assist. Participants identified two pressing problems that are currently not addressed appropriately: improving air quality and reducing congestion. These involve various sectors and policy domains, including transport, energy, housing, telecommunications and land-use planning and management. Our case study addresses these two inter-related challenges situating them at the nexus of the aforementioned sectors and policy domains.

In Cambridge, local commitments exist to reduce car use by 24% by 2031 compared to 2011 baseline numbers while improving air quality and keeping pollutant concentrations (NO2 and PM) within the safety limits set by national policy. These improvements will need to take place against a projected 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.

The first component of the comparative study is based on extensive web searches to develop an initial set of cities which have been implementing City Digital Twin type solutions to support local decision-making processes in planning and management. A set of 17 cities have been identified drawn from the global context which have been engaging with the concept of CDTs. The types of information we were seeking for in this initial screening phase include name, description, use cases, sectors involved, relationship to local smart city agenda and vision, intended users and implementation strategy and time frames. This comparative study is running until August 2019 and aims to understand generalisation possibilities from the Cambridge case study by providing a high-level overview of local factors the influence the local understanding and adoption of the CDT concept.

3.1 Data collection methods

This study was carried out using a qualitative research approach. Different sets of methodologies were employed to collect, analyse and code primary and secondary data. Concerning primary data, a total of 27 interviews were carried out, 5 community events attended and documented, two stakeholder workshops organised with an additional one set to take place on 15 July 2019. First, in-depth semi-structured interviews were carried out in the Cambridge city region, where respondents were selected to represent stakeholders with diverse roles in the relevant decision-making processes, including officers at all four government institutions, large employers, self-employed professionals, political figures, urban modelers, residents' associations and city-wide campaigning groups. The following table (Table 1) lists the interviews and a generic description of the respondents.

	Interviewee Anonymised Characteristics
1	Officer at local government, transport strategy
2	Officer at local government, energy projects
3	Officer at regional government, energy strategy
4	Officer at local government, planning and strategy
5	Officer at local government, air quality
6	Officer at local government, general policy strategy
7	Officer at local government, research team
8	Citizen activist, community forum
9	Officer at local government, transport modelling
10	Officer at local government, business intelligence research analyst
11	Councillor at local government
12	Citizen activist, artistic community
13	Business entrepreneur, independent co-working groups
14	Citizen activist, part of local government citizen engagement initiatives
15	Citizen activist, residents' association
16	Citizen activist, transport community group
17	Officer at local government, smart solutions
18	Citizen activist, residents' association
19	Officer at local government, transport strategy
20	Academia, urban modeller
21	Private sector, planning, policy, economics consultant
22	Business entrepreneur, independent co-working groups
23	Officer at regional government, transport strategy
24	Private sector, transport strategy for large employers
25	Officer at local government, citizen engagement
26	Staff at new development sites, general strategy and policy-making
27	Staff at academic institution, transport strategy

Table 1. Lists of interviews (Cambridge case study)

Second, we used methods of participant observation by attending community forums and public consultation schemes that tackled local issues of government engagement such as transport, land-use and planning. Third, the data collected from primary sources have been complemented with information gathered from national and local policy documents, technical and consultancy reports and outputs of previous research.

The data collected from these different sources were transcribed, anonymised and coded for data analysis purposes. The investigation focused on mapping the multi-actor governance landscape relevant to our two central challenges; the use of evidence by the different organisations, units and groups in relevant sectors; and the impact of evidence-use on decision-making and vice versa.

Regarding the comparative study, the initial screening of city cases where there has already been some engagement with the concept of CDTs involved extensive web searches to identify a broad set of cities from the UK, Europe and internationally. In the following months (July and August 2019), this initial list will be refined through desk-based research collecting information from the websites of the city councils and their external partners to better understand the local interpretations of the CDT concept. This large dataset will be used to select two to four city cases for more in-depth analysis, including also establishing contact with local authority representatives and relevant stakeholders to refine and test the results gained from web-based analysis.

4. Findings: case study and comparison

The results emerging from a plethora of data from the project are organised using a two-fold approach. The first is the detailed case study of the governance of a prototype city-level Digital Twin for the wider Cambridgeshire area. This section is divided into two axes beginning with the governance structures and processes of evidence production and policy-making in the public sector, followed by the citizen engagement and practices that have developed new insights into the digitalisation of city management in Cambridge. The second component is a comparative study of global experiences of digitalised solutions for smarter cities and the different iterations of digital twin approaches. This section will provide an overview of the data collected and analysed, and how these findings provide critical insights of the influence of governance structures and processes shaping the implementation of digital tools.

4.1 The Cambridge case study

4.1.1 Mapping the multi-actor governance landscape

A. 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.

On the 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 the 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.

B. 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). These will be further described in section 4.1.2.

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.

C. 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, '[l]ocal 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 to reduce 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 fewer 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).

4.1.2 Understanding citizen engagement and involvement

A. Public consultations and citizen voices in urban planning and management

Local decision-making follows national directives of public consultation as followed by local government in the UK-wide context (Cambridge City Council, 2019a). In Cambridge, several consultation models have been followed, as illustrated in Figure 2.

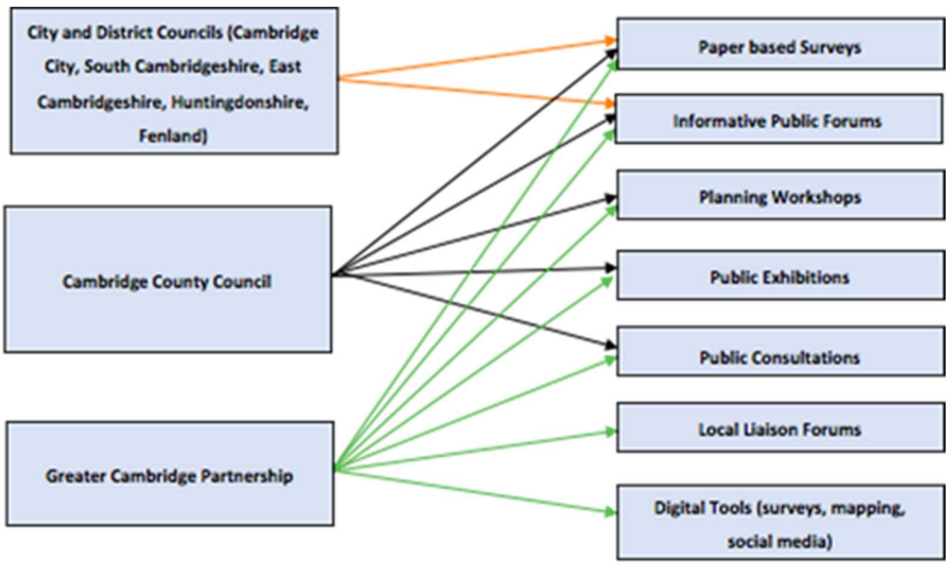

Figure 2. Different forms of public consultations currently in place in Cambridge

These top-down approaches have traditionally been used by different government entities to engage with citizens on the strategic vision of the city, consult place-based groups on particular project schemes, as well as communicate strategic and operational aims. Several issues have emerged with these traditional methods. First, citizens have reported that consultations are often more sporadic and spread over a long period of time. For example, in the case of the upgrading of the Fendon Roundabout in the South Cambridgeshire area, there was a three-year gap between two phases of consultations with residents in the area on the designing of the new roundabout. Second, the timing of these consultations remains contentious as citizens are often only consulted at a more advanced stage of planning. "[I]f you want change, then you are always disadvantaged. Because the response is 'we've [local government] already got the plans.' But you didn't ask us before you got the plans…" (Interview 8, personal communication, March 26, 2019).

Alongside the persistence of these traditional tools for public consultation, new approaches to citizen inclusion have been explored, especially by the Cambridge Partnership (GCP) to include more diverse voices and form a collective of different stakeholders. For instance, they created a new institutional form of consulting local residents on specific projects through 'Local Liaison Forums' (LLF). In the case of the of the 2018 Cambridge South East Transport Consultation, following an online survey, the LLFs serve as a meeting place for further discussion on current issues around the A1307 between Haverhill and Cambridge. These forums are chaired by local councillors and are usually organised biannually (Milton Road Residents Association, 2018). Their success however remains a matter of debate, such as in the case of the Milton Road Development. The Milton Road area had been earmarked since the 1980s as a potential development site for increased bus lanes, especially in light of the recent congestion surge to the nearby Science Park. Yet, these plans were halted by residents' groups across the Milton area such as the Milton Road Residents' Association, and the Hurst Park Estate Residents' Association, among others (Milton Road Residents Association, 2018). The GCP was forced to engage with citizens protesting the reduction of the land in the interest of bus lanes, and a long process of consultation through the Local Liaison Forums commenced. During this time, a series of internal changes to the county officers prolonged the process of including citizens' voices, but eventually many of the residents' demands were included. This experience proved that limited or lacking citizen inclusion at the design stage of proposed interventions can prove to be at great monetary and time costs for local development.

Nonetheless, consultation processes tend to be created later in the project's timeline, which limits the extent to which citizens' voices can influence decision-making. In fact, it has been essential for community groups to carve space in the policy sphere. These bottom-up approaches include first, the proliferation of residents' associations in different neighbourhoods – while parish councils in villages surrounding Cambridge city retain their strength in local decision-making. These associations vary in

size, interest and activity, but are increasingly getting involved in urban development and transport planning as the strategic-level commitment for economic growth became a key factor in shaping the agenda for local neighbourhood plans. Second, city-wide collectives have been able to secure a larger influence on policymakers, such as Smarter Cambridge Transport (SCT), through their strong convening power among community groups, and their use of influential data-driven forums and news outlets including a weekly column in the Cambridge Independent and social media analysis. Third, local councillors have played a role in involving citizens' directly in important planning mechanisms. For example, in the market-town of St Neots, the local district councillor has included an active professional self-employed group: the 'Neotists' on the steering committee for the Combined Authority's master plan for the town. The group's involvement in the designing of policies and plans for the town marks a milestone in recognising the importance of community participation.

B. Public Scrutiny and Accessing the Black Box

One issue that stands out regarding citizens' engagement with the evidence-base used to underpin urban planning and management decisions is their limited skills and accessibility to the modelling process in policy making and implementation; which have reduced trust in the evidence produced and a scepticism concerning data value.

To begin with, 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 data to provide evidence for decision-making. For example, when questioning figures in local government, community members tabled questions that involved interrogations on whether councils' have used urban and economic modelling to support land use planning and predict transport scenarios.

Some engaged citizens do have some understanding of difficulties and problems with local data collection. For example, several respondents brought up gaps in data collection for the Greater Cambridge Partnership's (GCP) Trip Chain Reports that were based on the evidence gathered through 2017 Automatic Number Plate Recognition surveys (ANPR) (Cambridgeshire Insight, 2017). These surveys are based on cameras recording traffic flow and bottlenecks to inform the GCP's future policy options for reducing congestion. However, engaged citizens were aware of the data collection methods and questioned the positioning of the cameras in the city, the type of skewed data they recorded, as well as missing cameras is important locations. Consequently, they have become increasingly sceptical of the accuracy and validity of predictions based on biased data collection methods.

Citizens also insisted that this data should be "displayed and made easily available to the public", signalling a grassroots recognition of the importance of data collection and the potential impact of the predictions based on these datasets (Greater Cambridgeshire Partnership, 2019b). As access to data and the models themselves is restricted due to contracting out and commercial interests, activists from citizen groups with an interest in transport have been facing difficulties when attempting to gain access. For example, the Smarter Cambridge Transport city-wide community collective relies on detailed data analysis to put forth alternatives for policies promoted by the different local authorities in Cambridge. Despite continued attempts to gain access urban models developed by consultants which underpin planning decisions, citizen groups have to bear the access cost of approximately £5,000 due to consultancy contracts and ownerships (Interview 17, personal communication, March 26, 2019). Thus, community activists have to resort to multiple sources to develop their alternative visions, and, as one activist put it, "just the investigative load of having to track stuff down is huge" (Interview 8, personal communication, March 26, 2019).

As a result, due to flawed data collection, conflicting policies and limited access to modelling assumptions, inputs and results, groups have expressed "endemic cynicism" (Interview 8, personal communication, March 26, 2019) when presented with the evidence used in urban planning and

management. They perceive that the messages they receive from elected councillors and government officers are conflicting which deepens trust issues in decision-making processes, as well as in the usefulness and accurateness of urban models and modelling outputs when it comes to deciding about real-world issues. Coupled with their lack of understanding of urban analytics, they remain sceptical of this type of evidence, especially if it is used to advocate for certain policies that disrupt their daily lives (such as the surge in new developments in the fringes of the city).

C. Holding 'Silos' to Account

Communities have continuously decried the 'silo-edness' of powers at both the strategic and operational levels. Citizens in their everyday interactions with the city, for example, have been faced with councillors and officers informing them that a certain problem is not within their remit, and are bounced from one government layer to the next even to submit a complaint. At the strategic level, citizen activists are quick to engage with planning activities of local councils, for example in the Queen Edith Ward. This particular neighbourhood located in the Southern Cambridgeshire District has witnessed increased citizens engagement with local government due to the nearby burgeoning (and opaque) expansion of the Cambridge Biomedical Campus (CBC). The CBC hosts multiple public, private and university organisations such as the Addenbrookes Hospital, the University's Clinical Schools and large pharmaceutical companies such as Astra Zeneca. It is projected to expand by over 4,000 jobs in the near future with the relocation of the Papworth Hospital and Abcam, with direct impact on the congestion and air pollution.

In an attempt to address the concerns raised by residents, county officers performed local 'walkabouts' to pinpoint gaps for cycling improvement as a means to better traffic conditions in the area. A few months later, residents were approached with the same request by the GCP team, revealing an apparent disconnect between different local public sector bodies and plans for implementation. A result of this lack of coordination is the staggering of accountability as citizens are unsure which council will be responsible for specific interventions or policies.

Addressing the lack of direct accountability mechanisms, the use of social media by different community activists has also been used to hold local councillors and officers 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. Here, a non-profit housing association is interested in increasing affordable housing in the area. However, residents' attachment to their communities and demand for methodological needs assessment have been vocalised and residents continue to protest ongoing planning. 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 citizens and strategies to limit disruption to the local community fabric.

In the 'virtual' public space of social media, different public bodies and citizen groups thus continue dynamic interaction on sites such as Twitter and Facebook, frequently citing conflicting reports, and the plurality of data used as evidence to inform policies. Through these virtual interactions many decisions are revealed as actually political decisions made using different sources of experience rather than a solid and comprehensive evidence base.

The above discussion illustrated that in some cases community pressure groups continue to have limited impact on local decision-making and its politics. In response, representatives of citizen groups have run for local offices such as city councillor positions (especially in the last few years), in an effort to shed light on the inability of local politicians to impact different layers of local governance. By running as independents, these citizens used local political platforms to highlight key transport issues (e.g. surrounding the Cambridge Biomedical Campus), and to entice local politicians to lobby for

increased representation at planning and transport committees. For example, the recent establishment of a joint planning department for Cambridge city and the South Cambridgeshire district aims to bridge fragmented decision-making across this geographical area. It remains to be seen how these efforts can impact spanning boundaries at the nexus and introduce wider institutional accountability across societal and organisational silos.

4.1 Comparative study

The second component of this project was to add a global dimension to understanding the reach and impact of Digital Twins worldwide. This approach aimed to trace the evolution of the concept of a Digital Twin and its adaptation to local contexts globally, as well as develop comparative parameters to analyse the influence of different governance structure and processes. First, a scoping exercise was undertaken based on policy papers from different countries, global indices of smart city indicators, and cross-country analysis in academic literature. A total of 17 cities at the national, European and international scales were selected for a more in-depth collection of data on the nature of the digital twin technologies employed in the cities, its application in city sectors and the types of stakeholder engagement embedded in the design. Of these cities, a larger number of UK cities were included in order to create future synergies between the Cambridge Digital Twin case study and approaches in the national context. Specifically, cities were selected that were purposefully implementing a 'digital twin' and in others, city-wide 'smart city' solutions were also analysed as they bore direct resemblance to digital twin conceptualisations (although not specifically named so). We found that different sectors that are being targeted by the application of digital twin technologies include telecommunications (fibre connectivity), parking and transit systems (rail), construction and real estate development (affordable housing), infrastructure management and operation (utility holes, smart bins), energy (thermal grids), climate (temperature and air quality sensors).

Thus far three factors have been identified as significant to developing cross-country comparative frameworks. First, the types of definitions used to identify digital twin technologies are yet to be consolidated into one comprehensive definition. In the UK the concept has been explored extensively due to the institutional and governmental backing by several institutions such as the National Infrastructure Commission, the Department of Transport, UKCRIC (urban observatories), the Centre for Digital Built Britain and the Digital Framework Task Group. The adoption of the City Digital Twin as a specific city-wide urban modelling approach is still being debated in the national context, yet many projects fall under similar ideologies of data collection (often with some real-time data feed from sensors), modelling and dissemination with local partners. The elaboration of a full city-scale exercise is yet to manifest in the UK. Whereas in Europe, digital twin technologies remain confined mainly under 'smart city solutions'. A prominent flagship European program has been the EU Horizon 2020 Triangulum project focused on smart city innovations and using three cities as a model 'Lighthouse City'- Manchester, Stavanger, and Eindhoven (Smith, 2018; Georgieva, 2019). In some of these cities different projects have come to resemble digital twin systems but remain confined to definitions and principles of finding smart solutions for city problems, rather than a holistic city-wide approach. Some cities are taking different approaches like Barcelona and Paris, which will be further explored in the extended duration of the Comparative Study period (July - August 2019).

A second factor shaping digital twin approaches that has been diversified across different countries is the forms and the use of Digital Twin technologies. These have oscillated from holistic approaches of implementing a city-wide model that incorporates a multitude of systems including construction, traffic and human flows, climatic sensors, and energy consumption among others. A flagship case of this type of use is the 'Virtual Singapore' model that is gradually being implemented across the city-state. However, in most contexts, there are a host of projects falling under the concept of a digital twin that

are regarded as the building blocks to building a comprehensive system. Some of the primary infrastructure for future digital twins are thus implemented with one specific sector based on the city's priorities. These projects once again diverged between strategic-level decision-making and operational and maintenance systems. For example, in the city of Stavanger, Norway, sensors have been developed to collect real-time temperature levels for bathers, while also a different set of sensors are used to support maintenance activities across the city. In this case, sensors have been deployed to prevent overflow of utility holes and prioritise and organise maintenance schedules of operation teams. Previously, it would take teams approximately two and a half years to complete one maintenance cycle, with slow responses to priority high-risk cases. Instead, this real-time technology has enabled the reshaping of city systems and responses (City of Stavanger, 2019).

The third factor currently identified as a significant comparative parameter concerns the different city approaches to data transparency, privacy and citizen engagement. As previously discussed in the literature review section, there is a significant research gap in unpacking how participation and transparency affect the success of implementing data-driven solutions. Debates in grey literature, the virtual space and in public culture have tackled issues of data privacy in light of recent global breaches, data ownership and access of third-party commercial interests, and the role of citizens in co-creating, collecting and verifying this data. All cities continue to grapple with these questions, with some placing participatory approaches at the centre of their strategies. For example, in Toronto, the US company Sidewalk Labs has won the proposal to redevelop an abandoned area in downtown Toronto, Quayside, to create a "smart, futuristic community of affordable housing, intelligent infrastructure, sustainable living and working spaces, and cutting-edge transportation and technology systems" (Qian, 2018). While this neighbourhood will operate based on data-driven systems, like Waymo-powered autonomous vehicles, community video, lidar and sensor systems (Qian, 2018), citizens are worried about data privacy issues and ownership that reflect concerns about city surveillance. As such, rigorous public debate has been ignited on this development, with Sidewalk labs exploring ways to include assessments of data use in their protocols, such as the map-based data collection mobile application 'CommonSpace' (Sidewalk Labs, 2019). Using a different approach, the city of Eindhoven has been claimed as a 'crowdsourced smart city' from the inception of the smart city solutions project as part of the EU Horizon 2020 Triangulum project (Georgieva, 2019). The city aims to put citizens 'front and centre' of all new solutions for the city, although this has remained confined to consultation processes and little interaction in the design of smarter systems, such as the smart lighting grid system (Smith 2018). As such, this particular parameter will pose some of the greatest influence in future digital solutions for smarter cities and requires a larger investment in participatory and grounded research to analyse citizen and stakeholder practices and engagement.

Conclusions

This research project developed seminal knowledge on the 'social' component of the adoption of novel digital tools in different cities with distinct local contexts. Specifically, we focused on the emerging concept of City Digital Twins (CDTs), and asserted that understanding the social component of technology design and implementation is crucial in moving the CDT concept beyond mere hype technology, towards a next generation of applied urban models which can support the development of more holistic responses to cross-cutting urban challenges. In the following, the conclusions are presented as recommendations for the design and implementation of CDTs derived from the Cambridge case study. Finally, we discuss early insights on context-dependent factors that affect the conceptualisation and adoption of CDT technologies in different cities in the UK, Europe and internationally.

The Cambridge case study highlighted the difficulties involved in developing effective and democratic participatory mechanisms in the city region due to the high number of interested and/or affected

societal actors (including public sector bodies operating at various political-organisational scales, private companies as well as the citizenry). The fragmentation of powers and responsibilities among a large number of stakeholders with various perceptions of the problem definition, possible solutions and pathways towards these makes it challenging to develop joint working in the face of nexus problems. Despite more recent developments, inadequate practices of public engagement persist, making it difficult for citizens to meaningfully participate in decision-making processes in urban planning and management through consultations. The apparent lack of transparency results in a 'black box' perception of data and modelling. Coupled with limited scope for scrutiny, this has been shown to create uncertainty regarding the value of evidence produced through modelling exercises to support decision-making. Moreover, data and evidence derived from modelling is still largely locked into social-organisational and sectoral silos in Cambridge. Our analysis demonstrated that this is especially problematic, where the siloed evidence base has a negative effect on the development of more holistic responses and negotiation processes for allocating responsibilities and accountability. This in turn can potentially lead to mismatch between the policies and strategies on paper, and implementation and action on the ground. Moreover, it also makes it difficult for engaged citizens and citizen groups to have their voices heard and influence urban planning and management decisions.

Based on our analysis, the Cambridge city digital twin, in order to succeed in becoming a next-generation urban model must aim to address the problems detailed above. By extension, it needs to contribute to transcending various silos across government levels and relevant infrastructure systems, as well as the public-private-third sector divide. In other words, a governance perspective on urban modelling and city digital twins highlights the necessity of evaluating such digital tools on the basis of their potential to support intermediation, boundary spanning and management among scarcely connected silos. This in turn necessitates the development of capacity and capability building processes both within the public sector and among citizens to be able to access, understand, commission and scrutinise applied urban modelling. By doing so, in-house city digital twins can contribute to developing more resource and time efficient, effective and democratic production of evidence, as well as improved evidence-informed decision-making in urban planning and management.

In addition to the purpose-driven approach to model development, user-centric requirements for the Cambridge city digital twin can be summarised as follows. First, it must be light-weight (able to run quickly on average computers) and user friendly enough (simple, intuitive) to be used in-house in various local authorities. By doing so, it will provide opportunity for refining the questions and options which may need to be explored through more detailed modelling requiring expert knowledge and contracting out (addressing the public-private divide). Second, the city digital twin needs to connect long-term strategic planning to short-term management through predictions and the monitoring of progress. This way it can provide useful and usable information for various public sector bodies with different responsibilities in urban and infrastructure planning and management and contribute to more joined-up working. Third, the Cambridge city digital twin must make use of existing models of infrastructure systems due to the scale of investment that went into developing these. The continued updating of sectoral models through the integration of existing and new data sources, and existing tested theories and new computational techniques (e.g. big data analytics, machine learning, artificial intelligence), remains key. Strategic links among such sectoral models, identified through combining scientific and practice-based knowledge, can become the backbone of the city digital twin evolving in tandem. By doing so, a prototype version of the city digital twin can already become a valuable tool to address nexus problems in Cambridge. Fourth, the city digital twin must be sufficiently open (but secure) and include an interface accessible to citizens to address transparency issues and provide opportunities for scrutiny. It also offers the possibility of developing new channels of communication between the public and market sector and the citizenry for consultation, information sharing and

feedback collection to complement and improve the existing practices, and to hold decisionmakers into account.

These initial findings provide a good starting point for building a better understanding how next-generation urban modelling tools, such as city digital twins, can contribute to addressing urban challenges that sit the nexus of various domains, systems and arenas for decision-making. 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 unpacking 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 decision-making 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. In the future we aim to further develop our approach into a new validation and calibration framework for next-generation urban models and city digital twins which goes beyond the currently dominant technology-focused approach.

Similarly, from the preliminary findings of the comparative study, a set of high-level factors for the design and use of digital twins have been developed based on the contextual parameters in each of the cities under analysis. First, an important context-dependent parameter affecting the use of digital twins is a historical review of the use and experience of urban models to support decision-making and the role of public, private and third sector stakeholders in this process. Since many countries do not have a long history of urban modelling and are just starting to build these capacities, the transformation to a city-wide system that is fully integrated will result in a different contextual environment free from residual stereotypes of the modelling process. At the same time, this accelerated adoption of digital tools will pose a new set of challenges for cities aiming to achieve smarter solutions with a new set of assumptions and evidence base. Second, data culture represents an important factor in how data can be and should be collected, institutional and legal ideology of data ownership and access, and a growing public consciousness on data privacy and equality. In some cities, such as collective societies, data privacy has not emerged as an issue, while in the Western context for example, legal and institutional mechanisms are constantly being made and unmade by the government-business nexus under increased public pressure. Third, and directly connected to these cultural factors, a dedicated socio-technical approach to critically analyse and assess the social, political, economic and technical impact of city digital twins will be vital to identify the success of these approaches. Socio-technical analyses in academia and policy literature have emerged as one of the key approaches to assessing how digital tools impact societal transformations and the spaces for participation, accountability and ultimately the consolidation of local democratic processes. By adopting a socio-technical approach to assessing the success and failures of smarter city technologies, cross-country analysis will deliver an in-depth understanding of how context-dependent factors may operate at a global level through homogenising technology tools, and yet are contingent on the socio-political evolution and interaction of technology at the local level. As previously described, these high-level factors will be further refined in the period between July-August 2019, where an in-depth analysis of two to four cities will include developing contacts with local stakeholders to refine these results and gain further insights into context-based processes.

Finally, this project has established the importance of refining socio-technical processes to gain in-depth knowledge of the impact of technological innovations in societies globally. Further research will be required to unravel the complex ways in which the social and technical spheres impact and transform their respective design, use, and governance. This research will be critical to advancing the evolution of City Digital Twins and their adoption at the local level for smarter policy-making.

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