A SOCIAL CONSTRUCTION OF TECHNOLOGY VIEW FOR UNDERSTANDING THE DELIVERY OF CITY-SCALE DIGITAL TWINS

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ABSTRACT:

This paper presents a novel conceptualisation for how city-scale digital twins (CDTs) can be better understood through the social construction of technology (SCOT) lens. This is achieved by drawing inspiration from sociotechnical studies of CDTs, and specifically the SCOT approach. Following a discussion of the shortcomings of technocentrism and techno-optimism bias in the CDT literature, a sociotechnical understanding of their delivery (i.e., conceptualisation, design, development, and implementation) is put forward. Delivering CDTs entails interactions between multiple stakeholders across sectoral boundaries and involve a confluence of business, social and technological dimensions which will engender several multifaceted and evolving complexities. Using the SCOT approach, the paper highlights how a CDT is not a static technical artefact, but rather a transient outcome from a technological network which co-evolves with the actors involved and the goals set in a place. Implications for understanding how an iterative approach for CDT development emerges in a place as part of city smartification agenda, the role of contextual factors in the social shaping of CDTs, actor participation and (ex/in)clusion are identified and discussed as potential future research directions to expand existing knowledge.

1. INTRODUCTION

City-scale digital twins (CDTs) are routinely deemed as a key tool needed for improved multi-party decision-making to tackle urban problems (e.g., reducing traffic congestion and mitigating air pollution) (Nochta et al., 2018). CDTs broadly represent virtual replicas or digital representations of the built assets and natural environment of cities that can be used as simulation environments for scenario development and testing (Nochta et al., 2021). The CDT-embedded 'Smart Cambridge' project (UK), for instance, explores "how data, emerging technology, and digital connectivity can be used to transform the way people live, work and travel" (Smart Cambridge, 2019: 2). The Sidewalk Toronto project by Google was meant to generate data from human and vehicular traffic to enhance city planning and development processes (Pittman, 2021). Both initiatives, like others elsewhere (e.g., Singapore and South Korea), place emphasis on data modelling and analytics in digital cities and CDTs, implicitly prioritising the development of an optimised technological solution.

Across policy, industry, and academic publications, much focus on CDT projects has been on "demonstrating the technical functionality of digital twin approaches to modelling, planning, and managing urban systems" (Nochta et al., 2021: 267). Techno-centrism and technology optimism bias characterise the ambitions that often accompany narratives around CDTs. This narrow focus on technical aspects of CDTs has contributed to shortfalls in existing understandings about CDTS. First, a neglect of the social (human – e.g., multidisciplinary viewpoints) and contextual (e.g., institutionalised practices, laws, and regulations) factors that influence the processes entailed in delivering CDTs for addressing city challenges. Delivery here, and throughout the paper, refers to the multi-actor processes of conceptualisation, design, development, and implementation (cf. Nochta et al., 2018, 2021). Second, an underdeveloped understanding of the multidisciplinary nature of delivering CDTs to address urban problems and improve people's quality of life. Finally, leaving unaddressed the context-specific nature of CDT projects, alongside the multi-faceted interactions involving technical artefacts (e.g., digital city models) and the different stakeholders who are engaged in the delivery of CDTs within specific socio-political contexts for meeting varied and conflicted objectives.

An emerging body of studies emphasize the need to view CDT projects through lenses that take into consideration both social and technical components (e.g., Nochta et al., 2021; Mora and Deakin, 2019). Sociotechnical studies of CDTs have indicated how CDT projects are influenced by different stakeholders coming from policy, research, and political angles with their own interests (Nochta et al., 2021). Indeed, according to Solman et al. (2022), the delivery of CDTs entails interactions between multiple stakeholders across sectoral boundaries and involve a confluence of business, social and technological dimensions which will engender several multifaceted and evolving complexities. Nochta et al. (2021) also highlight the influence of 15 different groups of actors representing private sector consultants, citizen groups, local public sector authorities, and national public sector bodies from their case study of the Cambridge CDT project. This multi-actor involvement is attendant with divergence in interests and call for negotiations to rally around a central goal.

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The context specificity of CDTs, and the multi-party involvements identified underscore how their development and implementation are inaccurately understood if examined mainly through lenses that privilege either social or technical dimensions only. A holistic understanding of the delivery of CDTs is better achieved through an approach that brings both dimensions into view and offers a comprehensive understanding of their mutually shaping relationships. This paper extends existing sociotechnical insights about CDTs by discussing how the processes entailed in their delivery to address city challenges is more holistically understood as an outcome of the social construction of technology (SCOT). The SCOT approach is distinctive in use for empirically investigating interactions between people, technology, and context-specific factors. The approach has been useful in unpacking the multi-faceted interactions involving humans, technical artefacts and contextual factors as part of developing and using technology in society (Surry and Baker, 2016), for infrastructure projects (Oti-Sarpong and Leiringer, 2021), and for highlighting the interdependent and conflicting interests that shape ICT-related personal data protection in smart cities (Breuer et al., 2019). We draw inspiration from the SCOT approach in critically synthesizing and discussing literature on CDTs. In using SCOT, technology is not treated as a mere stabilized object, but as an evolving socio-technical assemblage comprising artefacts, people, and their interpretations. Furthermore, technology, its environment, and the actors engaged with it are parts of mutual developments, evolving together via multi-faceted interactions.

The paper contributes in two ways. First, unpacking how conceptualising, designing, and developing CDTs to solve city-level problems all inherently entail social and technical components engaged in continuous mutually shaping processes. On one hand, the multi-party involvement in CDT projects suggest interactions among actors with potentially differing interpretations and viewpoints about technical artefacts (e.g., digital models), and about social aspects (e.g., governance, decision-making, ethical considerations) related to the use of data-driven solutions and digital tools to address urban challenges. On the other hand, (inter) national and local policy targets (e.g., decreasing traffic congestion, carbon emissions and improving air quality) also inform the nature and functional requirements of CDTs conceived and developed by a group of stakeholders in a place. Second, describing how the technical (e.g., physical sensors, digital models, and data) and social components (e.g., local laws and regulations, actors and their interpretations held) of CDTs undergo processes of mutual shaping with implications for desired city-scale outcomes. Concomitantly, we discuss how these components will co-evolve up to a (temporal) point where concerned parties would be convinced to varying degrees that specified goals (e.g., transport management for reduced carbon emissions) have been achieved. In doing so, we emphasize how a CDT is not a static technical artefact, but rather a technological network which evolves based on the actors involved, and the goal to be achieved at a given point in time. Based on these contributions questions for future research that relate to governance and inclusion and identifying dominant actors exerting most/least influence in shaping the form and function of CDTs are outlined.

The rest of the paper is organised as follows: Section 2 reviews relevant literature on CDTs, highlighting compartmentalisation in existing studies and the need to bridge these silos through a sociotechnical understanding. Section 3 argues how the compartmentalised view of CDTs, and more broadly smart city innovations, fall short in revealing their inherently sociotechnical nature which is subsequently described. Section 4 presents a sociotechnical view by describing the social construction of technology (SCOT) approach. The potential of using SCOT to develop a more holistic understanding of CDT initiatives is discussed in Section 5, and the final section outlines concluding arguments which call on researchers to embrace more sociological views of understanding smart city technologies and their implementation.

2. COMPARTMENTALISATION IN STUDIES ON CITY-SCALE DIGITAL TWINS

There is a plethora of studies on ‘smart cities’ (Mora et al., 2017). Despite the non-existence of a universal definition of the concept, existing literature offers frameworks guiding smart city development, emphasizing their technology, policy context, people and communities, economy facets (Pourzolfaghar et al., 2020; Chourabi et al., 2012), and for determining a city’s ‘smartness’ based on the nature of technologies implemented, and the performance of technologies developed and used to tackle urban problems (e.g., traffic congestion, waste management and, air pollution). Nonetheless, reviews of literature on smart cities indicate growing fuzziness about the concept, and emphasize growing attention to technocentric aspects, including complex analytics, modelling, and optimization of data capturing and analysis technologies to inform decision-making (Albino et al., 2015; Martin et al., 2018; Mora et al., 2017). This is despite awareness in studies that the creation of a 'smart' city using city-scale digital twins (CDTs), data capturing technologies, sensors and others technological components is integrated with an existing city's structures for daily living (Albino et al., 2015). This bias, critics argue, is a shortcoming that needs to be addressed through studies that adopt a more sociological approach to understanding the development and implementation of digital technologies to solve urban problems (e.g., Nochta et al., 2018, 2021; Mora and Deakin, 2019).

Among studies on city-digital twins (CDTs), which are part of the constellation of technologies developed and deployed to as part of creating a smart city (Nochta et al., 2018), the observed lob-sidedness in the broader smart cities literature is also prevalent. The concept of digital twins has been around since the 1960s, with origins traceable to the space industry, and later aerospace and manufacturing (Mora et al., 2017). In contrast, CDTs in the (urban) built environment is rather more nascent, only about three decades old. Often considered as a key tool for improved decision making in tackling urban problems, several CDTs have been developed and implemented as part of over 250 smart city projects implemented globally as of 2017 across cities in the UK, Singapore, Switzerland, the Netherlands, and the USA. The value of such projects, which stood at ~$40.1bn, is expected to grow to ~$100bn by 2026 (Smart City Tracker, 2021). Across these initiatives, there is strong emphasis on optimizing technological components of CDTs such as improving data transfer and increasing performance of digital twin communications (cf. Austin et al., 2020).

Although a universal definition for CDTs remains elusive, they are often described as virtual replicas or digital representations of built assets and the natural environment of cities used as simulation environments for scenario development, testing and informing decision making for tackling urban problems (Nochta et al., 2021). CDTs represent contemporary urban modelling tools for informing and improving city planning and decision-making, characterized by data-rich digital models of built infrastructure. Fundamentally, CDTs are underpinned by information communication technologies (ICTs) that allow for

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(remote) sensing, processing and transmission of data that can be analyzed to inform decision making (Batty, 2013). Indeed, Albino et al. (2015) notes that the deployment of digital tools and data for tackling urban problems has roots in the application of information communication technologies in cities – whether for producing built assets and infrastructure or to deliver services (Albino et al., 2015). Despite the touted potential of CDT, as forms of ICTs, to deliver benefits such as 'improved decision making', their development and use are saddled with problems. These include the unavailability or readily producible or usable data because there is no existing architecture to guide such a process, dispersed data ownership, competing commercial interests and a lack of data sharing networks. The multiple actors involved are also unable to effectively collaborate to realize benefits CDTs are espoused to bring.

In the growing academic and grey literature on CDTs, there is a significant degree of imbalanced compartmentalization in knowledge (Nochta et al., 2018, 2019). Majority of existing knowledge can be usefully grouped based on their focus on technical and social (i.e., non-technical) elements. Those in the former focus on optimizing technologies in the development of CDTs and emphasize their functionalities and predictive abilities. Studies are often premised on the idea that the future of urban systems will be defined by those with superior levels of functionality, performance, and efficiency. There is therefore a lot of attention to complex analytics, modelling, and optimization of data capturing and analysis technologies to inform decision-making (Albino et al., 2015). For instance, Austin et al. (2020) examined how to create optimized systems for urban systems supporting CDTs to inform decision making using semantic knowledge representation and machine learning. This group of literature is dominant in existing studies on CDTs and echoed across several review papers (Nochta et a., 2018; Albino et al., 2015; Mora et al., 2017).

Despite the dominance of technology-focused studies, an emerging body of literature argues for the need to focus on the 'social' aspects of conceptualizing, developing, implementing, and using CDTs. Here, social comprises human, contextual (e.g., laws, culture, regulations) and governance elements that influence the delivery of CDTs. Proponents of this view argue against technocentrism, and for the need to focus on human actors who shape technological components of CDTs to suit social contextual requirements. This view is partly on the basis that, beyond being promoters for smart city developments and the use of CDTs, people influence city-scale smartification agendas, and this can be better understood from a network perspective – in contrast to a focus on optimizing technical components (Nochta et al., 2021). City governance is also argued to be shaped by the implementation of CDTs. This change, Martin et al (2018) reveal, holds implications for inequalities, exclusion, and marginalization. Indeed, Kitchin (2014) and Batty (2018), for example, have argued that the deployment of CDTs as part of a city's smartification agenda holds the potential to deepen marginalization, and further disempower disadvantaged members of society (e.g., persons who experiencing poverty). Although critiques highlighting these issues have emerged, empirical evidence in existing literature confirming or rebutting whether decision-making driven by CDTs (dis)empower and marginalise citizens remains mixed. Widening citizen participation to include under-represented groups, as stakeholders, in the development and deployment of CDTs has therefore been identified as critical for any 'smart' city initiative (Ehwi et al., 2022). How community goals co-evolve with CDTs and other technologies towards a desired outcome is another area of related to the social dimension of CDT development and implementation which studies call for more attention. As an emerging body of studies, there remains vast potential for various social elements to be explored.

Insights from these two broad groups of literature have informed existing understandings of CDTs. The technology-focused body of literature has highlighted how technical functionality and optimization of CDTs, as ICTS could be achieved to better facilitate data-informed decision making in solving urban challenges. For instance, energy sensors being deployed to monitor patterns of consumptions and inform smart grids, and mobility sensors informing where to install additional traffic controls. Such insights, however, hold benefits, albeit limited, for directional decision-making processes where technological efficiency is prioritized for a desired outcome. It is against such prioritization that non-technical studies argue for the need to pay equal attention to human, community, governance, and contextual elements that influence or are impacted by the development and deployment of CDTs. This body of literature emphasizes, among others, how governance structures, social inequalities and contesting interests are impacted by decision-making backed by digital modelling and data from CDTs.

In both categories of literature, an implicit awareness that the conceptualization, design, development, and implementation of CDTs entails interactions between multiple stakeholders can be identified. Austin et al. (2020), for instance, propose a CDT operating upon semantic knowledge representation and machine learning to support data collection, processing, and automated decision-making. Despite the technocentric focus of this study, there is awareness of the multi-actor involvement in the development and implementation of CDTs, and the distributed nature of knowledge needed by city managers to make decisions. This is however addressed via an attempt to develop a more optimized CDT to guide city managers' decision making. Multi-actor involvement in CDTs is also captured through a distinction between different players and their focus – for instance, for hardware and software developers and vendors (e.g., IBM, Siemens AG), technological components needed for a smart city development are their focus (Albino et al. 2015). Non-technical studies also highlight multi-actor involvement in the delivery and use of CDTs, drawing attention to areas including governance (Nochta et al., 2021), citizen engagement (Ehwi et al., 2022), participation (Batty, 2018), (dis)empowerment, and social equity (Martin et al., 2018). This overlapping awareness of multi-actor involvement remains discrete. Thus, knowledge of how multiple actors (from different backgrounds holding potentially conflicting commercial/political interests) are excluded from, or play roles, in shaping the delivery and use of CDTs for addressing complex urban problems remains scarce.

The observed compartmentalisation in literature, critics argue, is holding back advancement of hybridised knowledge offering a consolidated understanding of interactions between the human actors, contextual factors, and technical components in delivering and using CDTs (Nochta et al., 2018; Mora et al., 2017). Following a review of literature, Albino et al. (2015) concluded that the development of a 'smart city' using a collection of technologies is fundamentally better understood as a context-specific initiative to meet local needs to obtain nuanced insights. Despite these critiques and calls, cross fertilization between these two broad compartments of literature on CDTs remains scarce. Particularly missing are studies adopting lenses allowing for examining, concurrently, both social and technical elements and their interaction, with regards to conceptualizing, designing, and implementing CDTs. An emerging group of studies are, however, diversifying the literature, and emphasizing the need for sociotechnical lenses to examine CDTs.

3. BRIDGING THE COMPARTMENTALISATION: SOCIOTECHNICAL STUDIES OF CITY DIGITAL TWINS

Studies are beginning to bridge the compartmentalization in literature by arguing for the need to understand, beyond a technology focus, the development and implementation of CDTs as dynamic change processes extending to a city's technological apparatus and the social environments that produce, maintain, and use them (Nochta et al., 2018). A key point of departure for sociotechnical studies of CDTs in the smart cities literature is contrasting utopian views that data collection, analysis, processing and sharing will solve all urban problems, with human actors being mere end users. Drawing inspiration from social science in studying city-scale technological innovations, Nochta et al. (2018), Datta (2015) and Martin et al. (2018), for example, emphasize the need to study citizens as not mere passive users of smart and digital technologies but rather active shapers with interests. Highlighting how technocentric studies often neglect a dynamic view of CDT initiatives and project their delivery as a static pathway to a normative end, Nochta et al. (2018) put forward how a sociotechnical view offers a radical alternative. They contend that such a shift allows for a processual way of evaluating city-scale developments in relation to technological innovations implemented, and their links with social, business, and environmental outcomes anticipated over time.

According to Nochta et al. (2021), three principles guide a sociotechnical perspective for studying the conceptualization, design, and implementation of CDTs. First, such a perspective goes beyond an examination of technical functionality of CDTs to unpacking aspects of trustworthiness and trust between proponents (e.g., city managers) and citizens. Undertaking the latter entails an articulation of the approaches used by representative actors in framing policy objectives to shape context specific model design and utilization to address urban challenges. Second, a sociotechnical perspective should lay emphasis on how the technical design of CDTs reflects context-specific characteristics (e.g., governance structures, processes) to enable successful implementation. This principle brings forward the need to understand the social (local) identity of CDTs, and not treat their technical components as detached from their origins and final place of use. Finally, using this perspective would help highlight resource provision and local adaptations needed to ensure that its implementation is successful. Doing so comprises detailing the human and organizational resources needed to equip a locality with what is needed to deliver desired CDT outcomes related to public value.

These three principles draw attention to using sociotechnical perspectives to contribute insights about CDTs with a focus on: the role of various actors, how they draw on contextual elements (e.g., local and national policies) and use them to frame CDTs in ways that engender trust among the network of actors engaged (including citizens); the localised identity of CDTs and; adjustments that need to be made within local structures to ensure success, and implications that might arise where they will be deployed. Aspects of the areas highlighted by the sociotechnical principles have been tackled in the few but growing sociotechnical studies of CDTs. Nochta et al. (2021) show from their study of a CDT project in the city of Cambridge (UK) that multi-actor involvement is evident, albeit shaped by potentially exclusionary structures. The different actors had different technical requirements for, and interpretations of the Cambridge CDTs. Local authorities and their external business partners were concerned with issues about: user-friendliness for in-house exploitation, functional alignment with (supra) national interests and ability to build on previous investments in modelling. Citizens, on the other hand, were interested in the functionality of the CDT for: communicating how data informs policymaking in a transparent and accountable manner, widening access and participation in democratic processes, and supporting community-led initiatives. This study's application of a sociotechnical view of the development and implementation of CDTs also revealed the importance of incorporating contextual requirements into city-scale technological innovations if any real changes are to be realized. In similar vein, from an extensive review of literature, and European and North American case studies, Mora and Deakin (2019) concluded that future of city-wide digital innovations should move towards a strengthened focus on their social shaping, and the interaction of the complementary elements of contextual knowledge, technologies, and desired community interests.

The findings from these studies to some extent, have helped bridge the observed compartmentalization in the literature. Nonetheless, a perspective that consolidates the three sociotechnical principles, while offering an understanding of how CDTs are delivered and used in a context, is yet to be seen. To address the observed shortcomings, we introduce how the social construction of technology (SCOT) approach offers a sociotechnical lens accompanied with a repertoire of constructs that are well-positioned to help unpack interactions involving social and technical elements of delivering and using CDTs. Concomitantly, we discuss future research directions the SCOT approach offers to help address less understood and hitherto unexplored sociotechnical dimensions of the conceptualization, design, implementation, and use of CDTs.

4. THE SOCIAL CONSTRUCTION OF TECHNOLOGY (SCOT) APPROACH

First proposed by Pinch and Bijker (1984) in opposition to technological determinism, SCOT presents an approach for empirically investigating interactions between people, technology, and context-specific elements (e.g., institutionalised structures, regulations, and professional practices). Technology is treated not as merely a stabilized object; rather, an evolving socio-technical composition comprising artefacts, people, meanings, and practices (Bijker et al., 2012). SCOT refutes technological determinism, and the approach allows exploration of how one iteration of the technology (out of many possible versions) emerges and stabilizes in an environment through cycles of alteration, variation, and selection (Bijker, 1995; 2001).

Three core assumptions guide the SCOT approach: Interpretative flexibility; social construction, and the dynamic heterogeneity of a technological network (Bijker et al., 2012). Interpretative flexibility captures how actors can alter the form and function of technology by ascribing different interpretations to its technical artefacts. Technical artefacts may be interpreted differently by various actors because they can be designed and used in diverse ways in each environment. Thus, the form and function of technology can vary based on its location and the composition of actors engaging with the configuration (Orlikowski, 2009; Leonardi and Barley, 2010). Fulk (1993) describe how actors in organizations share different collective patterns of meaning and action concerning communication technologies. In the smart city literature, the contents, application, understanding, and perceived utility of city digital twins (CDTs) have been shown to vary immensely across countries, professions, and city managers

(Albino et al., 2015). It follows that CDTs can undergo continual technological reconfiguration depending on context, required use and actors involved.

Technology being socially constructed means that it is neither fixed nor stable. Rather, its composition is deemed to be fluid, and its form and function evolve following alterations and adjustments in its network. Technology is therefore not permanently fixed, and it will undergo changes to suit where it is being used. Technology, therefore, emerges from a dynamic heterogeneous technological network comprising actors and technical artefacts and is shaped by contextual elements. Hence technology, its environment, and the actors engaged with it are not considered separately and governed by different rules. Instead, they are seen as parts of mutual developments and evolving together via multi-faceted interactions. See Kline and Pinch (1996) for an illustration from a study of the Ford Model T automobile. Thus, through the SCOT lens, technology is location-specific, dynamic, and evolving, based on the composition of its network in each environment (Bijker, 1995). Here the concept of a heterogeneous technological network represents a configuration comprising actors, technical artefacts, and elements of a given context that continually interact and co-evolve (Bijker, 2001).

The SCOT approach is operationalized through its constructs of Technological Frames; Relevant Social Groups; Problems and Solutions; Closure and Stabilisation, and the Wider Context (Bijker et al., 2012). A Technological Frame summarizes the interpretations actors ascribe to technology. It is the collective lens through which groups of actors interpret technology, which eventually dictates how the meaning of the technology will be constructed. Hence the technological frame is a product of thoughts, past experiences, and accumulated knowledge of similar technologies (Bijker, 1995; Leonardi and Barley, 2010). As a fluid construct, the composition of the technological frame is not fixed, and can constitute an array of actors' problems, goals, current theories, tacit knowledge, engineering practice (e.g., design methods and criteria) and specialized testing procedures. Collectively, actors (un)wittingly mobilize these to (re)shape technology to reflect their interests (Bijker et al., 2012).

Relevant Social Group refers to individuals (actors), organized or not, who coalesce around particular technological frames that represent their interpretations of a technical artefact. This concept is used here in relation to studying the emergence of a technology in a context, although a variant of it, as 'social groups' is applied in other constructivist theoretical lenses in socio political studies of broader society. Under the SCOT approach, a relevant social group can be identified if they share the same set of meanings attached to a specific artefact. Thus, they are grouped based on the proximity of their views about the technology (Bijker et al., 2012), rather than according to pre-existing professional, contractual, or organizational affiliations. Relevant social groups are technically artefact-specific, and their compositions do not remain static over the course of the technology's development.

Using various technological frames, actors may identify a variety of problems around technical artefacts. Problems are specific to relevant social groups, so what one group may see as a problem, based on a particular technological frame, may not be a problem for a group sharing a different frame. When problems are identified, actors in relevant social groups proffer solutions that, when accepted and incorporated, help (re)define the technology. Solutions, like problems, are specific to relevant social groups and a solution for one group may be the source of a problem for another. The incorporation of solutions helps reduce interpretative flexibility and realization of a localized iteration of technology that is firmer in composition.

Closure is reached by elimination of problems surrounding a technical artefact and stabilization results from an increasing perception among relevant social groups that a technological configuration needs no further modification. Closure and stabilization go together in the development of technology. Bijker et al. (2012) originally identify two cognitive mechanisms of closure, namely: rhetorical and problem redefinition. The former involves actors raising arguments to convince concerned groups that their perceived problem is not a problem, and the latter emerges when (usually dominant) relevant social groups identify certain properties of technical artefacts that distract attention from, or make negligible, other issues deemed to be problems. See Pinch and Bijker (2012) and for Oti-Sarpong and Leiringer (2021) for examples of closures.

The wider context refers to contextual elements (e.g., geopolitical, and socio-cultural environments, climate, legal regulations, conventions, and norms) that shape socio-technical interactions surrounding the development of technology. This may include organizational, industrial, sectoral, (supra) national, or international environments that contribute rich contextual information (Bijker, 2001). As such, the wider context is not merely a geographical locus for social and technical developments. Indeed, elements such as, socio-political situations, regulations, local and international laws and design standards (Oti-Sarpong and Leiringer, 2021 offer a detailed example).

5. A SOCIAL CONSTRUCTION OF TECHNOLOGY APPROACH FOR STUDYING CITY-SCALE DIGITAL TWINS: EXPLORING THE POTENTIAL

Understanding the delivery (i.e., conceptualization, design, implementation) of city-scale digital twins (CDTs) through the SCOT approach is predicated upon appreciating how interpretative flexibility, social construction and dynamic heterogeneity apply to such configurational technology. To this end, an important point of departure is that CDTs are technological configurations comprising different technical artefacts, situated within a heterogeneous assemblage of what constitutes a city, interacting with a diverse group of actors towards achieving goals that are constantly contested. Figure 1 captures this conceptualization.

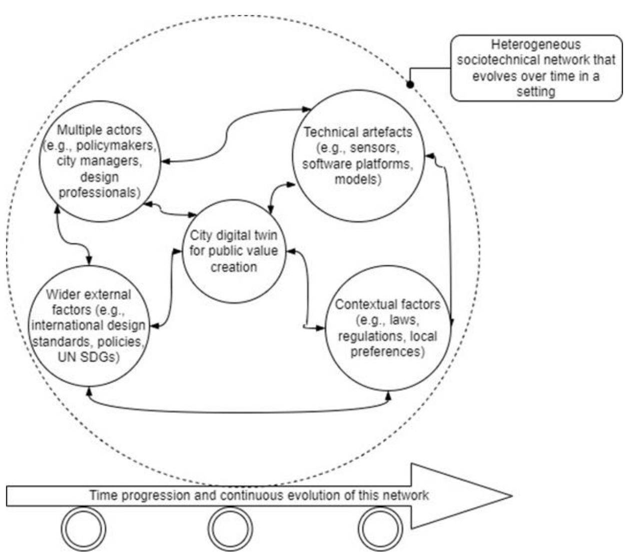

Figure 1. A conceptualization of CDTs delivery through the social construction of technology lens.

Taking forward the preceding view of delivering CDTs, we discuss here how applying the SCOT approach opens avenues to investigate complex sociotechnical aspects that are yet to be addressed in the literature.

The SCOT constructs are well-positioned for unpacking the multifaceted interactions that occur as part of the delivery and use of CDTs to better understand the involvement of multiple actors from different disciplinary backgrounds and with varied interests, the role of wider environment and contextual factors. Nochta et al. (2018: 121) from their study of a CDT project in Cambridge (UK) highlight that in practice their delivery involves "a multiplicity of local decisions subject to various political, social, economic and technical constraints". Decision-making is carried out by actors who enact them under influences that may be political, socio-cultural to varied degrees, and often not aligned. This observation, highlighted in other studies (e.g., Mora and Deakin, 2019; Breuer et al., 2019) is crucial for further understanding CDT delivery using the SCOT approach.

How a CDT – as a technological configuration – develops and emerges in a place is the central question that is followed to deploy the SCOT approach (cf. Bijker, 1995; Leonardi and Barley, 2010; Oti-Sarpong and Leiringer, 2021). This is critical for tracing all four groups of elements that are intertwined with the delivery processes (see Figure 1). Sensors, data analytics and modelling software, data transmitters and display panels, for instance, form part of a network of technical artefacts comprising a CDT (Austin et al., 2020). This constellation of technical artefacts is developed by various actors with specialised knowledge, following standards, and deployed within local/international regulatory boundaries in a place to achieve a set of outcomes (e.g., inform decision making to help curb traffic congestion). The development of the overall CDT is therefore aligned with the needs of a location, and therefore not context agnostic. Furthermore, the development of the technical artefacts of CDTs, and indeed the entire delivery process, cannot be taken for granted owing to the multiple actors involved, their differing interests and degrees of demonstrable power, and the need for context-specificity of the CDT. All these features constitute CDTs being products of social construction. Having multiple actors involved, for instance, suggests that several groups of interest would be at play. This is evidenced in Nochta et al. (2021) from their study of a Cambridge CDT project: local authorities were interested in having a technology that was user-friendly to exploit internally, and one that built on their existing internal modelling abilities. Citizens were keen to obtain a CDT that would facilitate transparency and accountability, and a tool to widen participation in democratic processes. It follows that the wider the network of actors involved, the more likely it is to have varied and (potentially) contesting views to be negotiated to arrive at a CDT that is deemed fit for purpose at a given point in time.

Over time, as societal needs and composition of actors change, so will the form and function of a CDT. This evolutionary view of CDTs and other smart city initiatives is useful for better understanding how changes in the compositions of city managers impact outcomes of digital innovation initiatives (Nochta et al., 2018). Here, the SCOT approach offers tools for a longitudinal analysis of the relationships between actor compositions in city-management, the type of CDTs delivered, and outcomes realised. Using the constructs of relevant social groups and technological frames, how CDT initiatives evolve alongside changes in the actors involved in their delivery and wider city management can be traced over time. This can help identify how different actor groups influence CDT and wider smart city initiatives in a place, leading to positive or negative outcomes (cf. Martin et al., 2018). For example, a key question raised among sociotechnical studies that can be tackled here is identifying the influence of political interests, and the imbalance of power among actors involved in delivering smart city initiatives (cf. Mora & Deakin, 2019). Such longitudinal historical analyses are possible using the SCOT approach to help inform future decisions to regulate various actor influences.

In delivering CDTs to tackle an urban problem, we argue that various groups of actors will coalesce around particular technological frames that represent their interpretations of the different technical artefacts forming a CDT. These relevant social groups, in SCOT terminology, will share similar sets of meanings based on which they will interpret and ascribe meaning to the CDT. The technological frames of the actors involved would not necessarily be formed based on pre-existing organizational, professional, or contractual roles, but shaped by their shared knowledge, past experiences, and accumulated knowledge of similar technologies. It is based on actors' technological frames about a CDT's technical artefacts (e.g., monitoring sensors) that processes of alternations and variations will occur, through the identification of problems and finding solutions for them. Sociotechnical studies about CDTs (e.g., Nochta et al., 2021), and the wider smart cities literature (e.g., Mora and Deakin, 2019), have already identified that actors bring multidisciplinary perspectives to city-scale digital innovation projects. This knowledge is key to unpacking aspects of actor involvement that remain unaddressed. The multidisciplinary nature suggests that views held are likely to be dissimilar and contesting interests must be negotiated to arrive at a CDT deemed appropriate for delivering set outcomes. The SCOT approach provides the tools to unpack how the multidisciplinary nature of city-scale digital innovation initiatives plays out to better understand stakeholder representation and degrees of influences in negotiations that shape CDTs, for instance (cf. Ehwi et al., 2022). Insights from such analysis would address concerns of potential mistrust, disempowerment and deepening of marginalization in society (Kitchin, 2014; Batty, 2018; Martin et al., 2018), and help identify the groups of actors who hold sway over how the form and function of CDTs come to be in different contexts, to inform models of actor configurations to ensure a balanced level of influence. This practical implication is crucial if largescale digital innovations will deliver desired public value.

The processes of negotiations to produce a location-specific CDT would require actors drawing upon contextual and wider environment regulations, design standards, data protection legislation, and discipline-specific methodologies. The SCOT constructs of wider context, and closure and stabilization, are useful tools for unpacking how these contextual elements are drawn upon in eliminating problems surrounding a technical artefact to a point where all actors involved perceive that there is no need for further modifications.

To illustrate the preceding, an example is offered. This is based on a city seeking to develop a CDT for the purposes of understanding citizen movement patterns and mobility choices to identify where bus routes might effectively help cut down the use of private vehicles, ease traffic congestion and by extension, reduce carbon emissions from vehicles. The range of actors for such a project would comprise city local authority representatives, activist groups for citizen transport, environmental/climate concern groups, transport owners, and city-level politicians. In addition, there would be technology developers / retailers, consulting firms, and financiers. The processes leading to deciding on whether to develop a CDT for the purposes of transport modelling, for instance, would ideally entail partner meetings and stakeholder engagements – where citizens would buy into, question, or reject the idea completely. On the one hand, the engagement of stakeholders with the idea of a CDT would be based on what they would be presented with from the city managers. In engaging with the idea, collectively, citizens will draw on their views of what such a CDT might help achieve, or possible unintended consequences that might lead to (e.g., red-lining certain parts of a city, or an imbalanced concentration of resources to improve transportation in affluent parts of a city). On the other hand, proponents who might have bought into the idea already would have varied concerns to be raised as part of the CDT development process. Actors with public finance interests might question the financial viability of such a project, and request for a more cost-efficient CDT design and operation. Public officials interested in data protection and wanting to ensure that prevailing laws (e.g., the UK's General Data Protection Regulation) are adhered to in the design of data gathering sensors and built into data analysis protocols to protect citizens. Technology developers and consultants may be interested mainly in the efficiency of the sensors or analytical tools being developed, influenced by international and local professional standards for the design and manufacture of any technical components, and focused on where they could be best placed within a city to gather the most reliable data. Climate activists might argue in support of such a CDT, given the potential benefits for cutting vehicular emissions, and citizen activist groups may raise concerns about potential breaches to citizen privacy from the data to be gathered. These varied frames by the different actors from the illustration highlight the different views that all bear on what might be seen as a simple process of developing a CDT in each location. After series of variations and alternations to the CDT based on the various views expressed through the process of development, a stabilised or 'final' iteration may be deployed. From a constructivist angle, however, this iteration is not deemed fixed perpetually. With time, as the needs of a city evolve, the application of the (previously stabilised) CDT might undergo changes with the involvement of a network of actors who would rarely be the same as those involved earlier (owing to changes in political appointments, job changes, procurement partner changes, for instance). Combined, these changes would start a new process of negotiations among actors to redetermine the nature and functions of a desired CDT which would then be newly developed or built from what exists for use.

It is worth noting that the extent to which these various groups might be involved in the process illustrated above is, again, context specific, and dependent on the institutionalised practices. Actors mobilizing these location-specific elements unwittingly bring to bear on the delivery of CDTs local and (inter)national institutionalized artefacts (e.g., standards, design protocols, professional standards), which are themselves products of social construction (cf. Oti-Sarpong and Leiringer). The question of how these elements bear on the shaping of CDTs and other largescale digital innovation projects remains unaddressed in existing knowledge. This is despite calls for legal frameworks and regulations to ensure that digital innovations do not lead to negative unintended consequences (Martin et al., 2018). The means through which closure and stabilization are achieved offer relevant insights into the tools actors utilize to shape the form and function of a CDT or any other technological innovation based on their interests. Using the SCOT approach to understand how this takes place holds relevance for identifying how progressive changes might be made to ensure city-scale digital innovation projects will meet public needs, build trust and function effectively (cf. Bolton et al., 2018).

6. CONCLUDING REMARKS

This paper extends calls for sociotechnical lenses to the study of CDTs by arguing that the delivery (i.e., conceptualisation, design, development, and implementation) of CDTs can be more holistically understood as processes entailing the social construction of technology. In extending the sociotechnical perspective for studying CDTs, we emphasize how the processes entailed in delivering CDTs all emerge from multifaceted interactions within a heterogeneous sociotechnical network. We argue that each of these processes entails the four groups of elements (actors, technical artefacts, contextual and wider environment factors), which encapsulate the social and technical aspects of CDT projects. Viewing CDTs this way, we argue, captures the principles of a sociotechnical perspective as put forward by Nochta et al. (2021), and opens avenues to further explore complex sociotechnical interactions entailed in the delivery of CDTs through a variety of network approaches, including SCOT.

By presenting how the SCOT approach offers tools for unpacking how CDTs emerge in different contexts, we highlight how aspects of actor involvement, degree of participation, and subsequent implications (e.g., inclusion, marginalization), as well as the influences of contextual elements, might be better understood. A future step is to analyse multiple case studies of smart city projects in the UK and Europe using the conceptualisation put forward in this paper to empirically demonstrate how a network approach like SCOT can help generate deeper understandings about the sociotechnical interactions that characterise the delivery of CDTs. It is worth noting here that SCOT is not a framework to guide the implementation of a CDT project. As an approach for empirically investigating how a configurational technology comes to be in a place, practically, it holds implications for identifying how non-exclusionary digital technologies might be developed and used in a place. The SCOT approach is neither limited by location, nor the kind of CDT, or smart city technology implemented. It is applicable to the study of technology in urban settings to better understand how their evolution impacts often overlooked social aspects of technological innovation initiatives.

The arguments presented in this paper are based on a critical engagement with literature on CDTs within the broader study of smart cities through the lens of the SCOT approach. Thus, the conceptualisation put forward draws on established seminal (e.g., Pinch and Bijker, 1984; Fulk, 1993; Bijker, 1995, 2001; Orlikowski, 2009; Bijker et al., 2012) and coeval studies (e.g., Leonardi and Barley, 2010; Surry and Baker, 2016; Breuer et al., 2019; Oti-Sarpong and Leiringer, 2021) that have demonstrated the utility of SCOT as a suitable approach for the study of technological innovations more comprehensively. As a position paper, the conceptualization of CDTs and arguments presented here are meant to direct attention in the emerging sociotechnical literature in smart city studies to adopt network approaches that will help examine the intricate relationships involving actors, technical artefacts and contextual elements which characterize city-scale technological innovations. Indeed, the fact that CDTs will rarely ever be the actual digital representation of the built environment (Batty, 2018; Nochta et al., 2018), draws attention to yet another layer of an evolving dyadic relationship between CDTs and the urban environments they represent. This fact also reinforces the need to continue using sociotechnical approaches to explore smartification agendas and CDTs to obtain a deeper understanding of the complex actor-artefact (digital/virtual)-context relationships entailed.

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