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Digital Twins for Smart Cities

Conceptualisation, challenges and practices

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Chapter 1
Introduction

In simple terms, a digital twin has been defined as

> a realistic digital representation of something physical (Bolton *et al.*, 2018, p. 11).

While digital twin technology has been in use in manufacturing and aerospace engineering for some time (see early applications developed by NASA for the Apollo programme (Rosen *et al.*, 2015)), simply replicating digital twin cases from these domains to city planning and management is likely to present a number of distinct challenges. The determining features of digital twins broadly agreed upon in engineering terms (see Bolton *et al.*, 2018; Niederer *et al.*, 2021) will require adaptation and refinement when applied in the urban context to address the inherent complexity of the various ‘socio-technical’ systems (systems made up of co-evolving social and technological elements) that constitute cities (Tzachor *et al.*, 2022).

Acknowledging the socio-technical complexity of cities entails recognising and avoiding over-simplifications in relation to the interactions between the different social and technological elements (sub-systems). In other words, we cannot simply ‘include people in the model’, as proposed by some industrial digital twin applications that incorporate ‘user behaviour’. In the engineering twins that incorporate user behaviour, the role classification and the way each user influences the systems of interest can usually be mechanically measured. However, the definition of ‘users’ (perhaps more appropriately, individuals, organisations, stakeholders and groups) in an urban context is vastly different from what is considered in a ‘conventional’ engineering setting. First and foremost, stakeholders and their influences are not external to the urban system and/or process being simulated. In fact, the nexus of stakeholder networks, their interactions with the built environment and the underlying power relations and negotiations *are* the systems.

While the techniques, knowledge and experience gained from developing engineering digital twins may underpin the development of city digital twins (CDTs), a simplistic approach relying exclusively on engineering methods, and aiming to optimise interconnected and interdependent urban systems without considering relevant non-technical factors, is unlikely to generate successful and meaningful outcomes. A new body of knowledge is needed to clarify the differences and similarities between manufacturing and city digital twins and identify good practice as well as opportunities and challenges in CDT development.

This book seeks to lay down the foundations of a socio-technical perspective for conceptualising, designing and implementing CDTs. It interrogates how efforts made at transferring the digital twin approach to city planning and management fit into a broader history of leveraging data and computational techniques to represent and predict interactions and their outcomes within and between urban form, various city systems and urban societies – with the aim of improving urban planning and management and outcomes for urban citizens. Further, scholarship from public policy and politics is drawn on to highlight societal processes and changes that are likely to have significant implications for the use of urban models and CDTs as decision-support tools and sources of evidence in relevant policy decision-making processes. CDT development is 'contextualised' with the findings to bring focus to the distinctive features of digital twins for cities.

As such, the aim of this book is to provide both conceptual clarity and practical guidance for supporting the development of CDTs. The book introduces the context, history and conceptual development of digital twin technology in **Chapter 2**. The proposed unique role, key characteristics and classifications of CDTs are then discussed in **Chapter 3**, which forms the theoretical basis for understanding the distinct features of city digital twins as opposed to engineering and/or manufacturing twins. This is followed by the practical challenges for developing purposeful, trustworthy and functional CDTs in **Chapter 4**, drawing on the 'Gemini Principles' (Bolton *et al.*, 2018) developed for built environment digital twins by the Cambridge Centre for Digital Built Britain. **Chapters 5 to 7** review a series of state-of-the-art practical CDT applications, featuring case studies provided by high-profile project leaders and experts in the field. The selection of CDT applications features a variety of spatial scales, geographical locations, sectors and policy domains. In **Chapter 8** a socio-technical interpretation of the 'Gemini Principles' is applied as an analytical framework to compare the different CDT projects, identify good practice and draw transferable insights. The comparison also highlights implications and suggestions for future CDT development, including key considerations for project planning and resourcing, technical design of CDTs, evaluation and upscaling strategy, and feedback mechanisms. Finally, **Chapter 9** revisits the theories of socio-technical change and reiterates the unique role of CDTs in supporting 'boundary spanning' as 'boundary objects', bridging silos across institutions, domains, sectors, disciplines and spatio-organisational and temporal scales.

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The BPDA is the planning and economic development agency for the City of Boston, Massachusetts, USA. By guiding physical, social and economic change in Boston's neighbourhoods, the BPDA seeks to shape a more prosperous, resilient and vibrant city for all. In May 2018, the BPDA launched a web-based 3D base model, a city digital twin (CDT) of the City of Boston, available for public use on the agency's website. The digital twin supports the BPDA's goal to implement new solutions to solve complex challenges facing Boston, while providing greater transparency and increased community engagement.

Boston was considered one of the first in the nation to launch a current realistic ArcGIS 3D smart model that integrates conventional GIS 2D data. The model builds on the city's commitment to ensuring city data is open and accessible to the public and has begun to integrate data from the City's Assessing Department, the BPDA's Article 80 process and results from Climate Ready Boston.

Boston's digital twin and GIS planning tools were awarded the Special Achievement in GIS Award at the 2018 Esri User Conference, and the model was presented by Carolyn Bennett, Deputy Director of GIS, Boston Planning and Development Agency (BPDA's), at the American Planning Association (APA) National Planning Conference in New Orleans, LA, USA in 2018. Later that year, Bennett showcased the digital twin in the ArcGIS Urban AGOL web application at the Esri User Conference in San Diego, CA, USA.

5.2.2 Applications

In addition to being available for public use, the digital twin provides BPDA staff with tools that will create real world visualisations for planning Boston's urban context. The model is used to support planning initiatives and strategic planning areas, review development proposals, as well as conduct in-house urban design studies, shadow analysis and zoning development capacity modelling. It will also serve as a tool to better understand the impacts of climate change and sea level rise on Boston's built environment.

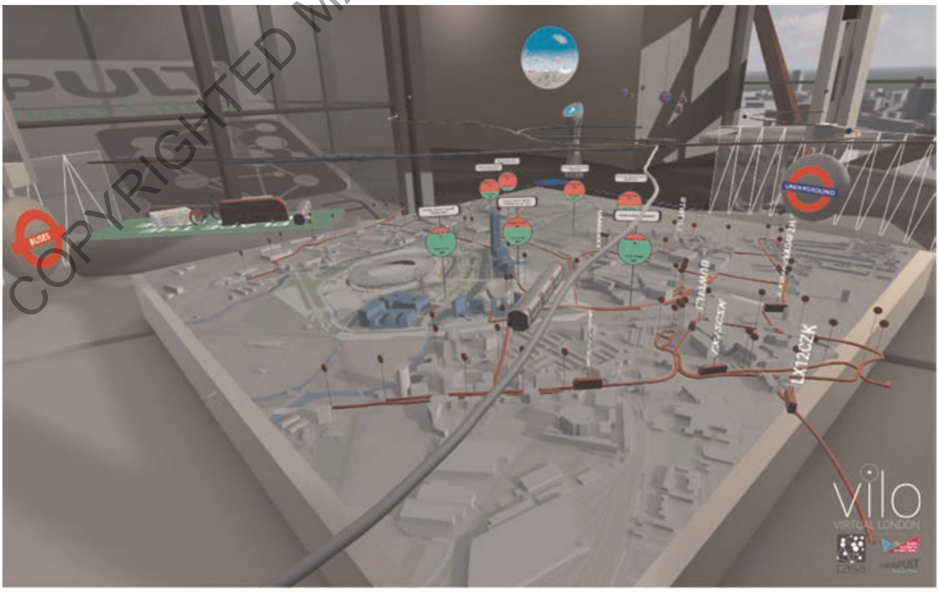
Figure 5.2 Boston Digital Twin – created using Esri scene viewer and published on ArcGIS Online

Using virtual reality technologies such as HTC Vive, data-rich virtual environments can be created in which users can freely interact with digital representations of urban spaces. In this demonstration, users are invited to enter a virtual representation of the ArcelorMittal Orbit tower, a landmark tower located in the Olympic Park. There are a number of visualisations of the ViLo platform on the Virtualarchitectures blog, the most general of which can be accessed at https://virtualarchitectures.wordpress.com/2017/09/18/vilo-and-the-future-of-planning/ (VA, 2017).

Using ViLo, it is possible to recursively embed 3D models of the surrounding district within that scene. These models can be digitally coupled to the actual locations they represent through the incorporation of real-time data feeds.

In this way, events occurring in the actual environment, such as the arrival and departure of buses and trains, are immediately represented within the virtual environment in real-time, as shown in Figure 6.5. VR is a technology which typically uses a head-mounted display to immerse the user in a 3D, computer-generated environment, regularly referred to as a 'virtual environment'. In this case, the virtual environment is a recreation of the viewing gallery at the top of the ArcelorMittal Orbit tower, situated at the Olympic Park in East London. The ViLo platform is then used to embed further interactive 3D models and data visualisations within that virtual environment. Two videos which illustrate this content and the way a user can explore the virtual and augmented environments that have been constructed can be found at https://vimeo.com/226303585 (virtual reality (VR)) (ViLo, 2017a) and https://vimeo.com/226279487 (augmented reality (AR)) (ViLo, 2017b).

Figure 6.5 Transportation facilities in the Stratford area within the virtual and augmented environment



critical process to understand and deal with conflicts and complementarities among different value interpretations across a range of interested and/or affected parties.

8.2.2 Trust: Openness versus security?

The Gemini Principles highlight that value creation and benefit realisation may be compromised by the lack of trust in the digital twin, especially public trust. Public trust, according to the Gemini Principles, is to be achieved through ethical design, and transparent, open and effective governance and regulatory arrangements for digital twins (Bolton *et al.*, 2018). In addition, from the perspectives of different stakeholders contributing to different digital twins (e.g. data and model owners), issues of security, liability and risk are also mentioned as part of creating trustworthy digital twins. Finally, ensuring data quality that is appropriate to the purpose at hand is seen as integral to trustworthiness for both stakeholders and the public.

Thus, although not listed among the trust-related principles of security, openness and quality, the role of curation (including governance and regulatory arrangements) is nevertheless emphasised in ensuring trustworthiness. The key focus seems to be on balancing security and openness. However, based on the CDT cases presented in earlier chapters, the perceived trade-off between openness and security may be, at least to some extent, misleading. This stems from an overly narrow understanding of openness as free and unobstructed access to the digital twin and the systems that support it, including the data, for all. While potentially different approaches to openness and transparency are mentioned, they are not discussed in detail in the Gemini Principles – not only in relation to data and the digital twin, but also the ways in which the outputs are used in urban policy and management.

Among the CDT cases presented in this book, the majority employ differentiated data access for the general public and for professional purposes. Access for the general public is often limited to schematic models and sample visualisations. One such example is the Boston 3D model which, beyond the visualisation components, also shares information on proposed projects (e.g. review proceedings) and environmental issues, such as the impact of projected sea level rise scenarios, with the ambition of incorporating archival applications to record the historical development of the city. Some CDTs further emphasise the importance of visualisation by incorporating virtual reality (VR) applications, such as the Herrenberg digital twin and London's ViLo. In Herrenberg, the expectation is that VR will improve participation and collaboration in planning processes. In ViLo, the focus is on creating an interactive immersive environment where different layers of data, some from real-time feeds such as public transport, can be selected, visualised and removed based on the needs and interests at hand.

It is notable that CDTs as communication tools most often are developed from 3D geometric models of the city. The Xiong'an case explicitly identifies the 3D visualisation (CIM model) as the first phase of CDT development for the city. Some CDTs go beyond communication as a sole means of interaction with the general public, such as the Zwolle DTLE pilots. Here, the general public are also regarded both as data contributors and active agents embedded in a multi-actor urban decision-making system, for example in dealing with climate change adaptation.