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THEMED INTERVENTION

Mapping

Digital twins and deep maps

Rob Kitchin[1] | **Oliver Dawkins**[2]

[1]Department of Geography, Maynooth University Social Sciences Institute, Maynooth, Ireland

[2]Maynooth University Social Sciences Institute, Maynooth, Ireland

Correspondence
Rob Kitchin, Department of Geography, Maynooth University Social Sciences Institute, Maynooth, Ireland.
Email: rob.kitchin@mu.ie

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Abstract

Mapping is now thoroughly digital at all stages of production and maps are widely used in digital form. This digital turn has transformed the nature of mapping and maps. Maps need no longer be static representations, but rather constitute spatial media, providing an interactive, dynamic means for creating, discussing, and sharing spatial information and mediating spatial practices. This has included the development of 3D mapping, including nascent digital twins and digital deep maps. In this short paper, we reflect on our attempts to produce a 3D city information model for Dublin that acts as a basic digital twin, which we have also used to explore deep mapping, as well as map projecting data onto a printed 3D map model of the city. We consider what digital twins and deep maps mean for how we understand the nature of mapping, arguing that they produce a dyadic intertwining of map and territory; a literal, material expression of post-representational, ontogenetic conceptions of mapping.

KEYWORDS

3D mapping, deep maps, digital twins, map projection, spatial media, virtual reality

1 | INTRODUCTION

Since the 1960s, mapping has increasingly become digital to the point where paper maps are now simply analogue renderings of digital databases, which store born-digital data generated through a variety of digital instruments (e.g., surveying tools, sensors on satellites and drones) and processed using specialist software packages. This digital transformation has radically altered the nature of mapping and maps. GIS systems enabled bespoke map layering of spatial data and to conduct spatial analysis and modelling, becoming ever more sophisticated over time. The internet enabled the development of the geoweb: distributed GIS; online, interactive, and searchable mapping; geo-referenced and geo-tagged data; user-directed mashing together of spatial data; participatory and crowdsourced mapping; and the interlinking of varied data such as map layers with photos, video, audio, and user-generated comments and content. New forms of mapping visualisation have proliferated, including interactive map interfaces, dynamic displays that update in real-time, landscape and 3D views, and innovative and interlinked visual analytics. Maps need no longer be static representations of spatial information, but rather constitute spatial media; that is, they are a dynamic means for individually and collectively creating, accessing, and sharing information, and they mediate spatial practices and facilitate communication and dialogue (Kitchin et al., 2017).

This process of digital transformation is far from over and in our work we have been exploring the development of 3D spatial media, and moving beyond mapping as representation towards mapping with a deeper, more sustained connection between map and territory. In this short paper, we reflect on our attempts to produce 3D spatial media for Dublin, including a basic virtual 3D city information model and map projecting data onto a 3D printed model of the city. We consider the concepts of digital twins and deep maps, the challenges and politics in realising their production, and what they mean for how we understand the nature of mapping. Our 3D spatial media work has been taking place in the context of urban planning and has also included interviews with practising planners about use cases and adoption (Kitchin et al., 2021).

2 | 3D SPATIAL MEDIA AND DIGITAL TWINS

Analogue visualisations and 3D mappings of geographic environments, including perspective views, elevations and sections, photomontages, panoramic images, architectural renderings, and physical models, have long been produced and used in urban planning (Levy, 1995). Since the 1990s, these have been complemented by digital 3D spatial media, including computer aided design, virtual and mixed realities, 3D GIS, building information modelling, and city information modelling that enable spatial and aspatial data to be linked to and viewed within 3D representations of geographic environments. In addition to traditional map information, 3D models also encode the geometric structure and visual appearance of objects in the landscape (e.g., terrain, buildings), and can also include their physical properties and interrelationships. The 3D models are often interactive and dynamic and facilitate the addition of new information, such as newly proposed buildings and planned developments.

In our recent work, we have been particularly interested in the development of nascent city information models (CIMs), including their presentation through virtual reality (immersive viewing and movement through the 3D landscape). A CIM consists of a 3D model of the urban landscape in which other spatial and semantic data can be attached and viewed (including real-time data and 3D models of planned buildings and infrastructure) and simulation models can be run under different scenarios (e.g., shadow analysis, flood and traffic models) (Thompson et al., 2016). CIMs align with the notion of urban digital twins (Cureton & Hartley, 2023), which is being championed in the UK and elsewhere as a means of meaningfully representing geographic space and managing urban systems and infrastructures over time (Bolton et al., 2018).

A digital twin involves the coupling of a material object or system and its digital representation, which are linked via an iterative and reciprocal flow of data and information (Grieves & Vickers, 2017). The digital representation is also intended to function as a simulation environment, which can be used to test interventions intended to bring about particular desired states of the material entity, and ideally provides a mechanism to effect those changes. With respect to urban governance, a traffic control room effectively constitutes a digital twin mediating traffic flow, with real-time data relating to traffic movement modulating the traffic model, which then alters the traffic light phasing and how vehicles move on streets. The digital twin can be used for testing, monitoring, simulation, guiding maintenance, and to manage its physical twin over its lifecycle, with these processes delegated to automated algorithmic processes or undertaken through human supervision.

While CIMs are often digital mirrors of city landscapes – with accurate topology and topography and realistic building and landscape rendering – most are far from being digital twins in terms of a synchronous interconnection. Some changes in the real world can be reflected in the model, such as the display of real-time sensor data, but this is limited in nature with significant alterations to the urban landscape only being updated in the model infrequently. Such changes presently need significant organisational effort in data collection, processing, and management, and to be supported by large, multi-agency collaboration. Yet CIMs and the promise of digital twins have captured the interest of: government, with respect to urban management and governance, formulating and assessing urban planning, and the monitoring of city services and policies; architectural, construction, and planning businesses seeking a means to develop and sell urban designs and plans; academics for producing urban simulations and models and to facilitate participatory projects relating to local places; and civil society organisations interested in new kinds of counter-mapping initiatives that might open up new political conversations about urban development. Many other use cases are yet to be developed; for example, CIMs could provide a means to explore issues of volume and verticality in cities (Harris, 2015).

3 | CREATING CIMs

Our own attempts at producing a CIM for Dublin have been more digital mirror than digital twin in nature. Producing the CIM was far from straightforward and there was no off-the-shelf, plug-and-play solution when we started. Moreover, there was no readily available high-resolution, detailed 3D model for the city. After extensive searching and enquiries, our project became the test partner for a new national 3D dataset produced by Ordnance Survey Ireland, which consists of a digital elevation model plus 3D buildings at LOD2 (level of detail 2: block shapes but no roof or finer building relief or façade details). We supplemented this dataset by manually adding in buildings constructed after its creation. The software options for producing CIM were fairly limited. Game engines such as Unity and Unreal Engine that produce a high-resolution and responsive visual display and allow interactions within and with 3D environments do not natively support real-world geographic coordinate systems and are not designed to handle geo-referenced data. Initial model building was undertaken in CityEngine, a 3D GIS platform. We subsequently switched to using FME, a spatial ETL tool, which assists with the transformation and management data. The results were then imported to Unity, which interacted with a custom API serving the data. Other spatial data at the building-level scale is limited to a handful of datasets (e.g., planning applications, property price), with the vast majority of publicly available data published at a coarser spatial scale. It was, however, possible to parse in any geo-referenced data, including real-time data relating to transport and environment (e.g., location of buses and trams, bikeshare use, sound sensor readings), and to run simulations such as flood-level rises, shadow analysis, and viewsheds (see Figure 1). The model is interactive and clicking on a building will open an information pane. In more recent work, we have produced a more photo-realistic 3D model of the city using Caesium and Unreal Engine (see Figure 2). These difficulties in sourcing 3D mapping and other spatial data are common globally.

In addition to the CIM, we 3D printed a physical model of the centre of the city onto which we could project data (see Figure 3). The model is 1:2000 in scale and is 3.5 m (7 km) by 2 m (4 km) in size. The model possesses terrain topography and buildings, including small features such as garages and garden sheds, and large heritage features such as sizeable monuments. Using a data projector with a wide-angle lens, maps and other spatial data can be projected onto the model, effectively turning its relief into a textured 3D screen. Any data that can be displayed in the CIM can be cast onto the printed model, including the real-time data. We have been using this model in the Data Stories project to produce planning and property

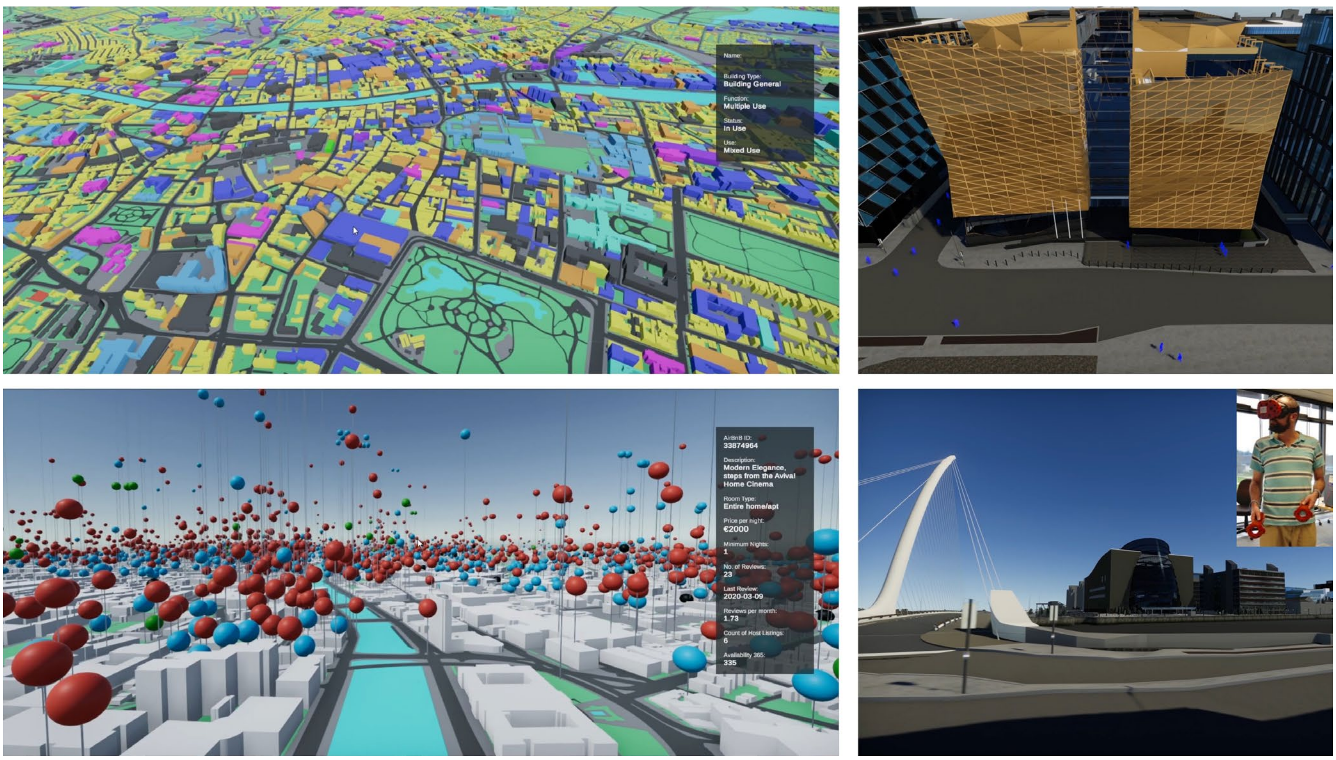

FIGURE 1 Dublin CIM produced by the Building City Dashboards and Data Stories project.

FIGURE 2 Dublin in Caesium and Unreal Engine for the Data Stories project.

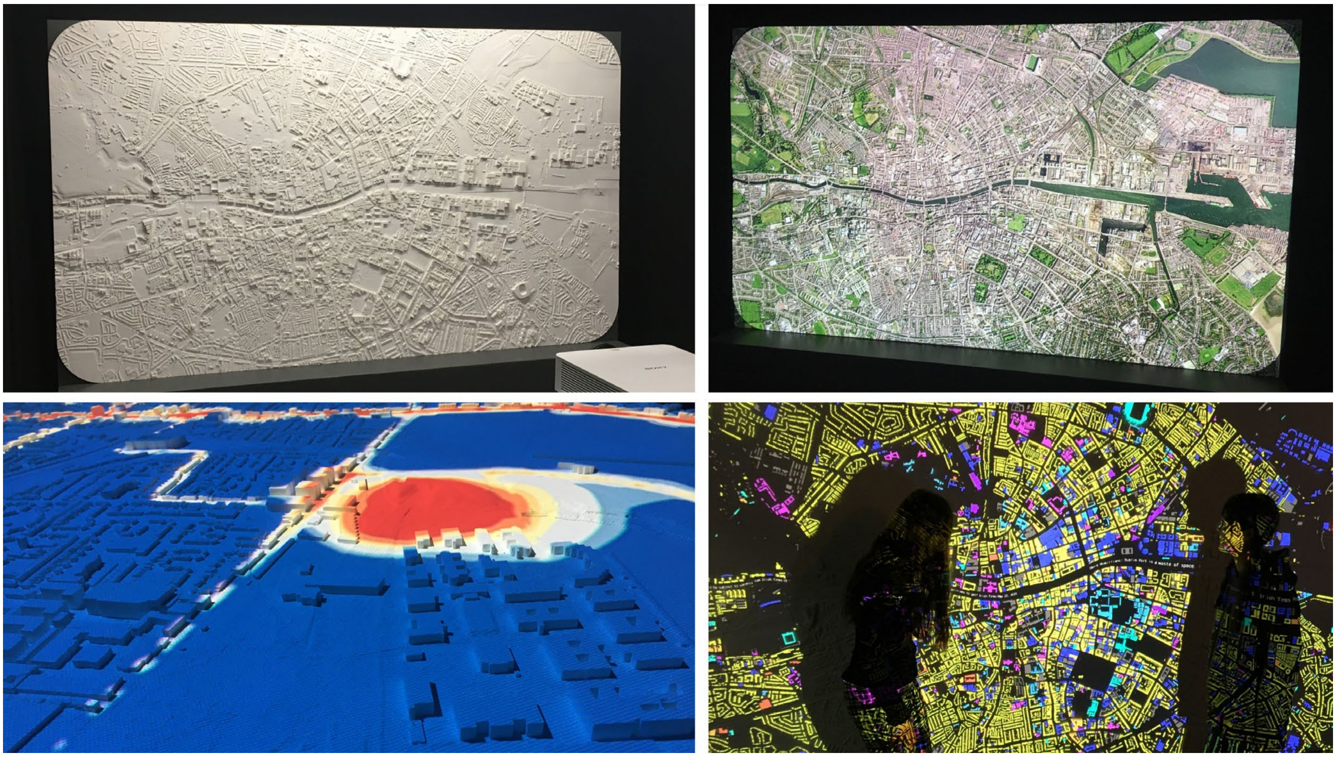

FIGURE 3 Dublin 3D printed map model by the Building City Dashboards and Data Stories projects.

stories that the public can view at exhibitions. It is clear that the experience of viewing a 3D map model that displays a series of static and dynamic (real-time or animated) data is qualitatively different to viewing a set of static, flat maps.

Our research has revealed practical and political issues in producing CIMs, along with epistemological issues in their underlying formulation of geographical knowledge. As with maps and GIS (and urban informatics more generally)

(Kitchin et al., 2016; Pickles, 2004), there is a politics to how CIMs are produced in terms of the stakeholders involved and their intent, choices, and negotiations in design and implementation, and a data politics regarding what data are utilised and produced. In addition, CIMs adopt and privilege a realist epistemology, wherein the 3D model is positioned as homologous to an urban environment, the data displayed in the model are cast as objective and representative, and software and its algorithms are neutral and commonsensical. Yet, as extensively argued in the literature on smart cities, urban data and technologies are not objective, neutral, and value-free, and nor is their use; rather they are saturated in politics (Kitchin & McArdle, 2017). Moreover, CIMs and their use as digital twins to manage the city reduce and atomise complex, contingent relationships and issues, sheering them of the contextual frames of history, policy, culture, and systems of governance, thus providing a limited means to understand urban processes. As such, just as critical cartography and critical GIS have sought to reveal and recast the politics of mapping, a similar approach needs to be adopted with regards to CIMs and digital twins.

4 | DEEP MAPS

We have also examined ways in which our 3D spatial model can be used as a platform for creating deep maps (Dawkins & Young, 2020a, 2020b). A deep map understood in terms of mapping practice (Bodenhamer, 2022) – as opposed to a literary sense (Heat-Moon, 1991) – aims to supplement a base map with a range of other contextual information about the place that is usually difficult to incorporate as map layers, such as (auto)biography, personal and collective memories, stories, folklore, and natural history to create a multimedia, textured sense of a landscape and its people. Here, a quite different notion of a digital twin is being produced, one centred on seeing cities as constellations of places and communities rather than as a set of systems. An urban digital twin maps and reacts to factual data and is largely peopleless; at best, individuals are datapoints in the system (e.g., unknown passengers on a bus, residents in an area). A deep map by contrast seeks to capture a sense of place and community, the nuances of everyday life, and the unfolding of historical change through the inclusion of spatial narratives and personalised multimedia content (photos, videos, documents, audio). While the digital twin provides a single, coherent mapping, a deep map presents the multiple perspectives of different actors and the contested unfolding of places.

The creation of a deep map might involved the replication of the visual appearance of the landscape at a particular time in which multimedia content is accessible, but it might also be the landscape as it was understood personally by inhabitants (for example, drawn as a sketch map). In other words, while the digital twin presents an objective, synchronous mapping, the deep map aims to produce a more situated and contingent mapping. In our case, we have enabled multiple users to engage with each other using avatars within our virtual 3D model of Dublin, and to place self-generated digital media (such as scans of local landmarks and points of personal interest) into the landscape (see Figure 4). Nonetheless, our 3D deep map is Cartesian and avowedly Western in its operation and conception of space. This raises questions concerning Indigenous forms of spatial knowledge and Indigenous mapping and how Indigenous deep maps that do not adopt a Cartesian form might be captured and presented in 3D form. Such questions highlight the need to consider how the notion of decolonising cartography (Rose-Redwood et al., 2020) might be applied to 3D spatial media.

5 | 3D SPATIAL MEDIA AND THE NATURE OF MAPPING

3D spatial media, and in particular digital twins and deep maps, prompt critical reflection on the nature of mapping. The 3D nature of CIMs raises questions regarding its relationship to what we traditionally refer to as maps (2D spatial representations). Are 3D spatial models simply maps with an additional axis (x, y, z)? If we take the definition of a map as 'graphic representations that facilitate a spatial understanding of things, concepts, conditions, processes, or events in the human world' (Harley & Woodward, 1987, p. xvi), then 3D spatial models are fundamentally maps. Functionally, a 3D spatial model captures the same spatial measurements and relations as maps, they can be used for the same purposes such as navigation and locating and visualising spatial data, and the same interactive functionality available in GIS and online mapping can be implemented. They also use similar processes of abstraction, generalisation, and scaling. However, the relationship between user and mapping alters with a 3D spatial model, particularly when it is viewed as virtual reality (VR) and augmented reality (AR). When wearing a VR headset, the user is immersed in the spatial model, viewing it as if located in the geographic environment. Further, they can walk and fly through the model, or even teleport between locations. In AR, such as a heads-up display, the 3D spatial model overlays the geographic environment (one

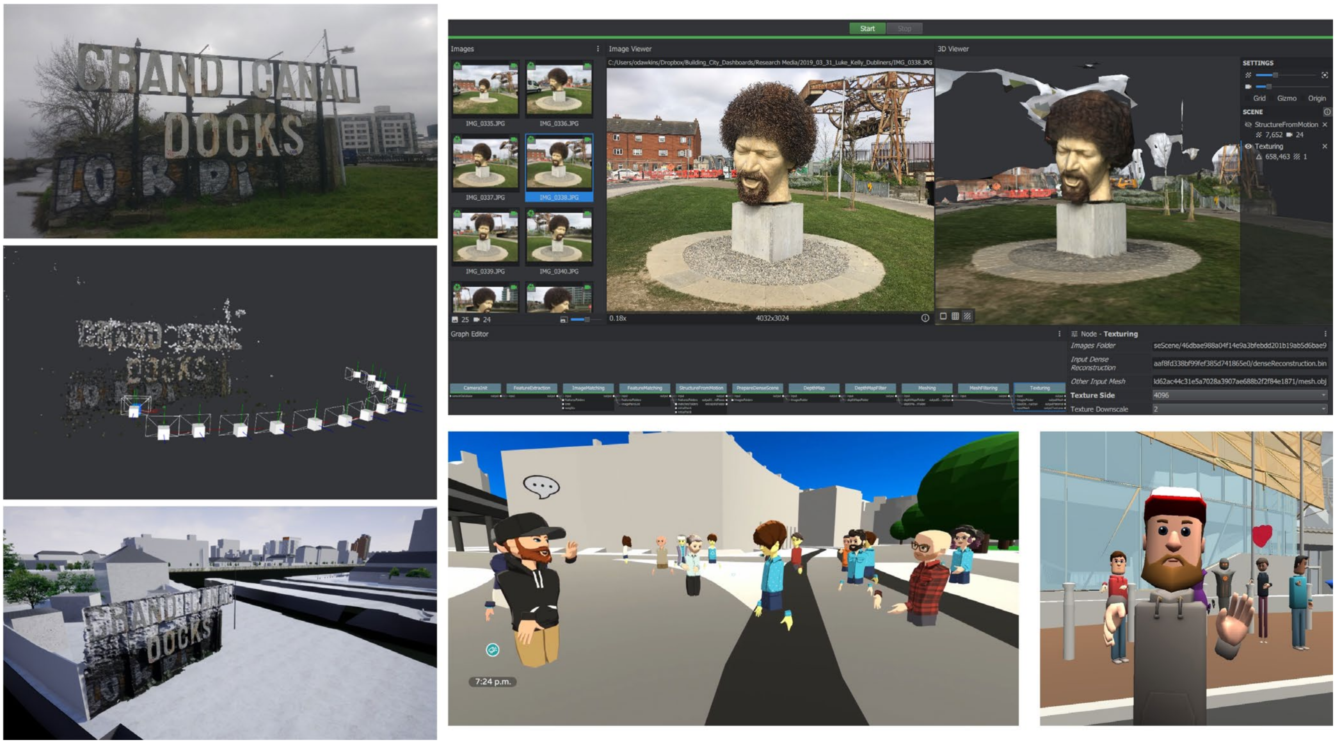

FIGURE 4 Dublin digital deep mapping created by the Building City Dashboards project.

can see both model and landscape in an aligned form). In other words, in both VR and AR, the mapping is experienced in a fundamentally different way. This raises some significant questions about the perceptual, cognitive, and experiential relationship between users and mappings. Similarly, the multimedia nature of 3D deep maps, wherein a diverse set of other material and media (memories, stories, photos, videos, audio) are fused with the mapping, prompts questions relating to the extent to which maps have become media; that is, a means by which other information is communicated.

In addition, digital twins produce a more intensive and sustained connection between map and territory – they become dyadically intertwined with a change in one directly affecting the other, potentially in real-time. This is a quite different relationship than between a traditional map and territory, in which the map bears a representational correspondence, but there is no dyadic, material fusion. Moreover, while a paper map is fixed in form, a CIM produced as a digital twin (even as a digital mirror) is not static, but dynamic – viewable from different perspectives and changing in sync with alterations in the geographic space. Here, a digital twin is a literal, material expression of post-representational, ontogenetic conceptions of mapping (Kitchin & Dodge, 2007); digital twins are inherently dynamic, always materially of-the-moment, not simply through how they are engaged (unlike paper maps that are static representations but are always contingently and contextually re-made every time they are used). Likewise, the development of 3D deep maps is ontogenetic in a literal sense, particularly when their production is participatory and ongoing as new material is continually added to the deep map. But even if the deep map is published in a fixed form, its interactive nature and multiple user-directed routes through which to view the map and its associated content mean the map and how it is experienced and understood is emergent.

Geographic digital twins in the form of CIM and digital deep maps are still in their infancy. Undoubtedly, both will increase in sophistication, with CIMs moving from digital mirrors towards twinning. The nature of maps will continue to evolve demanding new ways to make sense of mapping.

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DATA AVAILABILITY STATEMENT

Data unavailable.

ORCID

Rob Kitchin https://orcid.org/0000-0003-4458-7299
Oliver Dawkins https://orcid.org/0000-0002-5294-4375

REFERENCES

Bodenhamer, D.J. (2022) The varieties of deep maps. In: Bodenhamer, D.J., Corrigan, J. & Harris, T.M. (Eds.) *Making deep maps: Foundations, approaches, and methods*. London, UK: Routledge, pp. 1–16.

Bolton, A., Butler, L., Dabson, I., Enzer, M., Evans, M., Fenemore, T. et al. (2018) *The Gemini principles: Guiding values for the National Digital Twin and information management framework*. Cambridge, UK: Centre for Digital Built Britain and Digital Framework Task Group.

Cureton, P. & Hartley, E. (2023) City information models (CIMs) as precursors for urban digital twins (UDTs): A case study of Lancaster. *Frontiers in Built Environment*, 9, 1048510. Available from: https://doi.org/10.3389/fbuil.2023.1048510

Dawkins, O. & Young, G.W. (2020a) Engaging place with mixed realities: Sharing multisensory experiences of place through community-generated digital content and multimodal interaction. In: Chen, J.Y.C. & Fragomeni, G. (Eds.) *Virtual, augmented and mixed reality. Industrial and everyday life applications*. Cham, Switzerland: Springer, pp. 199–218. Available from: https://doi.org/10.1007/978-3-030-49698-2_14

Dawkins, O. & Young, G.W. (2020b) Workshop—Ground truthing and virtual field trips. In: Economou, D., Klippel, A., Dodds, H., Pena-Rios, A., Lee, M.W., Beck, D. et al. (Eds.) *6th international conference of the immersive learning research network*. San Luis Obispo, CA: IEEE, pp. 418–420. Available from: https://doi.org/10.23919/iLRN47897.2020.9155213

Grieves, M. & Vickers, J. (2017) Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems. In: Kahlen, J., Flumerfelt, S. & Alves, A. (Eds.) *Transdisciplinary perspectives on complex systems*. Cham, Switzerland: Springer, pp. 85–113. Available from: https://doi.org/10.1007/978-3-319-38756-7_4

Harley, J.B. & Woodward, D. (1987) Preface. In: Harley, J.B. & Woodward, D. (Eds.) *The history of cartography, volume one: Cartography in prehistoric, ancient, and medieval Europe and the Mediterranean*. Chicago, IL: University of Chicago Press, pp. xv–xxi.

Harris, A. (2015) Vertical urbanisms: Opening up geographies of the three-dimensional city. *Progress in Human Geography*, 39(5), 601–620. Available from: https://doi.org/10.1177/0309132514554323

Heat-Moon, W.L. (1991) *PrairyErth: A deep map*. Boston, MA: Houghton Mifflin Company.

Kitchin, R. & Dodge, M. (2007) Rethinking maps. *Progress in Human Geography*, 31(3), 331–344. Available from: https://doi.org/10.1177/0309132507077082

Kitchin, R., Lauriault, T.P. & Wilson, M. (2017) Introducing spatial media. In: Kitchin, R., Lauriault, T.P. & Wilson, M. (Eds.) *Understanding spatial media*. London, UK: Sage, pp. 1–21.

Kitchin, R., Maalsen, S. & McArdle, G. (2016) The praxis and politics of building urban dashboards. *Geoforum*, 77, 93–101. Available from: https://doi.org/10.1016/j.geoforum.2016.10.006

Kitchin, R. & McArdle, G. (2017) Urban data and city dashboards: Six key issues. In: Kitchin, R., McArdle, G. & Lauriault, T. (Eds.) *Data and the City*. London, UK: Routledge, pp. 111–126.

Kitchin, R., Young, G. & Dawkins, O. (2021) Planning and 3D spatial media: Progress, prospects, and the knowledge and experiences of local government planners in Ireland. *Planning Theory and Practice*, 22(3), 349–367. Available from: https://doi.org/10.1080/14649357.2021.1921832

Levy, R.M. (1995) Visualization of urban alternatives. *Environment and Planning. B, Planning & Design*, 22, 343–358. Available from: https://doi.org/10.1068/b220343

Pickles, J. (2004) *A history of spaces: Cartographic reason, mapping and the geo-coded world*. London, UK: Routledge.

Rose-Redwood, R., Blu Barnd, N., Lucchesi, A.H., Dias, S. & Patrick, W. (2020) Decolonizing the map: Recentering indigenous mappings. *Cartographica*, 55(3), 151–162. Available from: https://doi.org/10.3138/cart.53.3.intro

Thompson, E.M., Greenhalgh, P., Muldoon-Smith, K., Charlton, J. & Dolník, M. (2016) Planners in the future city: Using city information modelling to support planners as market actors. *Urban Planning*, 1(1), 79–94. Available from: https://doi.org/10.17645/up.v1i1.556

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