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CITY DASHBOARDS AND 3D GEOSPATIAL TECHNOLOGIES FOR URBAN PLANNING AND MANAGEMENT

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Introduction

Data has long been generated about cities to make sense of them, manage services and infrastructure, solve urban problems, and produce urban policy and plans. Indeed, managing data across the data life cycle (generating, handling, storing, analyzing, archiving, sharing and destroying) is a key activity of city administrations and other public agencies. Traditionally, data are generated as a by-product of core administrative functions (such as routine bureaucracy), as a core function of infrastructure or service (such as traffic management), or through routine and commissioned surveys (such as household surveys or a census). These data provide key inputs for strategic development planning (such as creating local area plans), assessing proposed planning applications, and operational governance (such as the delivery of services).

Since the early 1990s, and through the adoption of Agenda 21 of the United Nations Conference on Environment and Development (UNCED) in particular, cities have been mandated to systematically monitor sustainable development and adopt evidence-based decision-making. To that end, cities have sought to gather and use available data to compile city indicators (recurrent quantified measures) that enable key aspects of urban life (economy, labor markets, health, education, transport, housing, etc.) to be tracked over time (Maclaren, 1996; Innes and Booher, 2000; Van Assche et al., 2010). New managerialist approaches to the public sector emerged which promoted the use of indicators to monitor the performance of cities and city administrations and track the implementation and consequences of policy initiatives, to make public services more efficient, effective, transparent, and value for money (Behn 2014; Kitchin et al., 2015). Urban indicators also enable benchmarking that establishes how well a neighborhood/city is performing vis-a-vis other locales or against best practices (Huggins, 2009). More recently, the open government agenda, and the drive to create open government data, has sought to make both the underlying data and urban indicators open for the public to scrutinise and use (Kitchin, 2014a). Also, such initiatives often seek to make operational, real-time data (such as environmental sensing, weather sensors, bike share, car park spaces, real-time passenger information) available through various web services and APIs.

These core datasets and indicators provide key inputs for applied urban data analysis intended for both professional audiences (planners, managers, technocrats, policymakers) and for public consumption. One of the key means by which the results of these analyses are disseminated is through city dashboards. Here, a suite of visual devices ranging from numeric displays to analytical charts is used to display indicator data through a common graphic interface. This may also incorporate interactive elements enabling users to query specific data. More recently, city dashboards have been complemented by the development of 3D geospatial tools that transpose city-data onto a three-dimensional landscape representations of the city. In this chapter, we discuss the form of applied data analysis conducted with city dashboards and emerging 3D geospatial tools. We contend that these spatial media provide a valuable means to make sense of often complex data, especially for those that lack the skills to create their own data visualisations, though they are not without critique and shortcomings. We discuss some of those criticisms and indicate ways in which they might be addressed.

City dashboards for urban planning and management

City dashboards provide a visual means to organise and interact with data. They use visual analytics – dynamic and interactive graphics (e.g., gauges, traffic lights, meters, arrows, bar charts, graphs, maps; see Figure 6.1) – to display and communicate information about the performance, structure, pattern, and trends of cities. Key data are displayed on a screen and, in many cases, can be interacted with (e.g. selecting, filtering and querying data; zooming in/out, panning and overlaying; changing the type of visualisation, or simultaneously visualising the same datasets in different ways to explore their dimensions and identify their relationships). Because the data used are recurrent, quantitative measures, many of the visualisations that are used show change over time and are updated as new data are released. By utilising the power of the visual to summarise and convey a large amount of information, dashboards enable a user to quickly and effectively explore the characteristics and structure of datasets to identify patterns and interpret trends. As such, they act as cognitive tools that improve a user's 'span of control' over voluminous, varied, and quickly transitioning data (Brath and Peters, 2004). Indeed, city dashboards are becoming increasingly popular with city governments and agencies because they collate different streams of data and diverse sets of indicators into one system, with a complement of additional tools to visualise, query, and analyses them. Moreover, they allow users to track and compare changes over time and space, and in the case of real-time data, the here-and-now of different phenomena. The power and utility of city dashboards are premised on their claims: to show the state of play of cities, on overview and details, through objective, trustworthy, factual data; to translate the messiness and complexities of cities into rational, detailed, systematic, ordered forms of knowledge (Kitchin et al., 2015).

Figure 6.1 Examples of types of interactive graphics used in city dashboards

Source: Thingsboard, 'Real-Time IoT Dashboards' examples; https://thingsboard.io/ (accessed December 28, 2020).

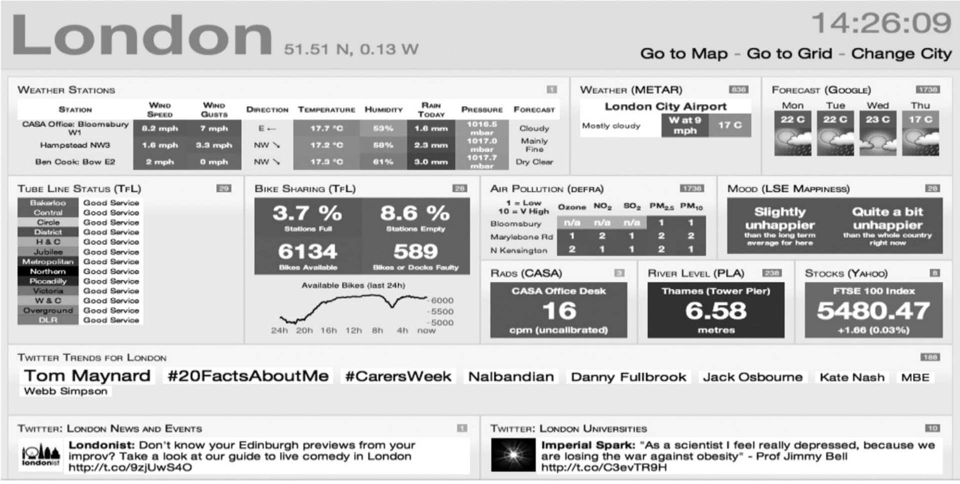

Figure 6.2 City-at-a-glance dashboard

Source: CASA, London Dashboard, http://citydashboard.org/london Created by the authors in 2015

In some cases, the dashboard acts like that of a car or plane, with relevant data 'consolidated and arranged on a single screen so the information can be monitored at a glance' (Few 2006: 34). An example of such a dashboard is the London dashboard created by CASA at University College London (see Figure 6.2). Analytical dashboards are more extensive in scope and are hierarchically organised to enable a plethora of interrelated dashboards to be navigated (typically on a thematic basis, such as planning or health), and afford summary-to-detail exploration or 'drill down' within a single system (Rivard and Cogswell 2004) (see Figure 6.3). Analytical dashboards are more likely to include map interfaces that enable the spatial distribution of data to be examined, with these maps typically being interactive. Both types of these dashboards are common in urban control rooms, but they are also increasingly being displayed in mayor's offices, public buildings, and made accessible to the general public via dedicated websites.

While city dashboards have much utility, they also have several shortcomings and criticisms. Kitchin and McArdle (2017) detail six main concerns, which they frame with a set of questions:

- Epistemology: How are insight and value derived from city dashboards?
- Scope and access: How comprehensive and open are city dashboards?
- Veracity and validity: To what extent can we trust city dashboards?
- Usability and literacy: How comprehensible and useable are city dashboards?
- Use and utility: What are applications and value of city dashboards?
- Ethics: How can we ensure that dashboards do not cause harm and are used in a socially responsible manner?

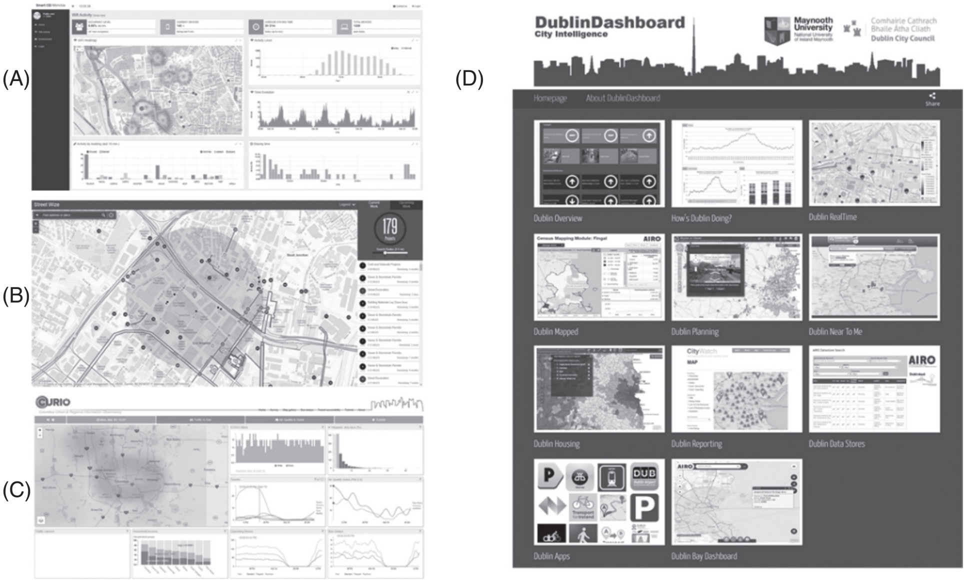

Figure 6.3 Analytical city dashboards

Source: A. Madrid dashboard (ceiboard.dit.upm.es/dashboard/); B. Los Angeles dashboard (https://navigatela.lacity.org/streetwize/); C. Columbus dashboard (http://curio.osu.edu); D. Dublin Dashboard (www.dublindashboard.ie) Created by the authors 5/10/2018

Their analysis builds on a long history of critique concerning the politics and praxes of the development and workings of spatial media such as GIS, location-based services and locative social media (Kitchin et al., 2017; Pickles 1994; Sheppard 2005), raising several fundamental and instrumental concerns about how city dashboards produce knowledge about cities and how they are used in urban planning and management. Rather than reject the use of city dashboards outright, Kitchin and McArdle (2017) instead prefer to recognise their utility and value as a mode of communication and means of making sense of the city. Their caveat is that for city dashboards to reach their full potential, issues relating to the access, quality, comprehensibility and limited scope of data will need to be addressed, as well as a more fundamental reframing of their implied epistemology through the adoption of ideas from critical GIS and radical statistics.

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Building a city dashboard with user engagement

The Building City Dashboards project[1] has sought to extend initial work on the Dublin and Cork Dashboards[2] by addressing the critiques identified in their initial development.

[1]dashboards.maynoothuniversity.ie (accessed December 21, 2020).

[2]dublindashboard.ie and corkdashboard.ie (accessed December 28, 2020).

Specifically, this has involved a fundamental rethink in the presentation of visual analytics and the tools provided to users, primarily based on user engagement research and requirements analysis. Typically, city dashboards are engineered as data portals that perform specific, pre-set functions with little thought given to the holistic effects of their functionality, usability, and user experience. This has become apparent in our user interviews where respondents were invited to provide feedback on four different city dashboards (Young and Kitchin, 2020).[3] It was found that many participants did not have sufficient data literacy, familiarity and competence with the use of dashboards to find relevant materials and interpret the data visualisations presented to them. The first principle of Hansen's 'User Engineering Principles' is to 'KNOW THE USER' (Hansen, 1971). In the context of city dashboards this means that their creators should make efforts to consider the specific requirements, skills, and knowledge of their intended users. As fundamental as this principle is, feedback from our interviews indicate that knowledge and understanding of user requirements is assumed without meaningful engagement of potential users in the process of scoping and design. Speedy delivery of data dashboards can have great utility in addressing short-term exigencies, but in the context of city dashboards this can be tokenistic and compromise their ongoing relevance for professional stakeholders and citizens. Creating sustainable and open city dashboards requires an informed awareness of how and why different groups of users engage with data through city dashboards to learn, think about, and frame questions about typical urban concerns. For example, our research demonstrated that complex, proprietary GIS software was too difficult to use and the functionalities provided were too specialised for many users and use cases. While a skilled user with strong data literacy and familiarity with the tools could gain significant insight from the dashboards and visualisations produced by these tools, most other users struggled to extract value from the experience, abandoned their sessions, and are unlikely to return. More generally, while city dashboards profess to bring data and insight to the masses, in reality, they are used by a small cohort of advanced users, in the main because this is the only group with the sufficient skills to use the tools and interpret their outputs. However, they were not the only group with an interest in evidence-based approaches to understanding the city.

A key issue is to produce dashboards that can be used by novice users but also still provide the tools required for more specialised uses. While acknowledging the diversity of users, pragmatic steps must be taken to develop actionable designs that address differing user requirements and cognitive styles, enabling designers to effectively determine the appropriateness of presenting tabular information over graphs, words in place of numbers, or structured rather than open-ended systems (Shneiderman, 2010). Our research identified two complementary approaches. The first is an engagement with the graphic, map and web design literature with reference to established guidelines for design and navigation

[3]Dublin, New York, London and Hawaii's dashboards.

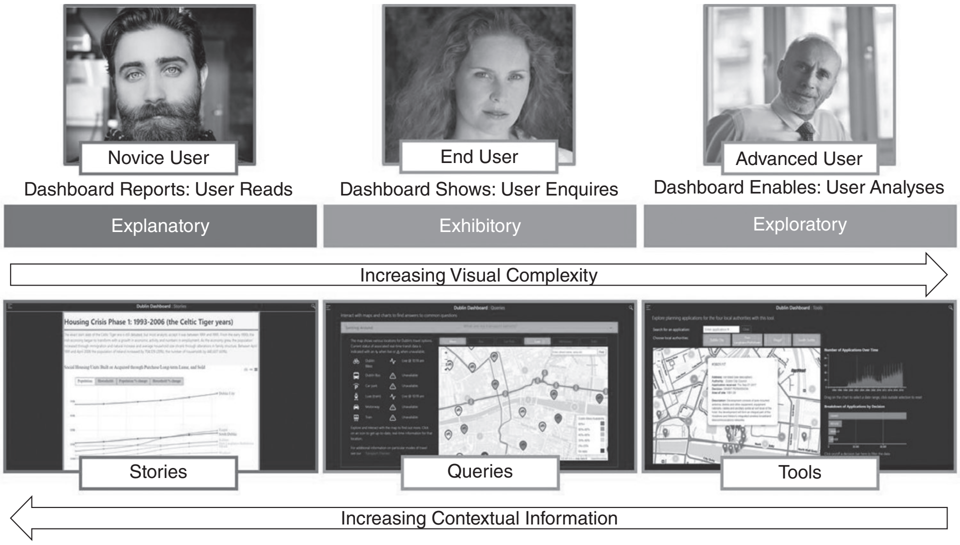

Figure 6.4 Personas

(e.g. Bollini, 2017; Kelleher and Wagener, 2011; Shneiderman, 2010; Tufte, 2001). The second involved the creation of three personas (Josh, Jane, and Geoff), each representing a potential type of user ('novice', 'end-user' and 'power user') defined along two axes – experience (casual to professional) and domain knowledge (simple to complex) (see Figure 6.4). An 'end-user' is typically someone such as a planner or policymaker who has a reasonable level of data literacy but is not a professional analyst with advanced skills. In re-designing the Dublin Dashboard, we have sought to be mindful of Josh, Jane and Geoff, and their respective profiles and to consider the balance between the complexity of analysis and contextual information; between explanation and exploration. In addition to a more standard thematic organisation of information we have sought to structure the dashboard around three further modes of presentation – stories (simple data visualisations with accompanying explanatory text), tasks (for more complex and comparative data visualisations), tools (additional data analytics functions beyond data visualisation and access to the underlying data), also depicted in Figure 6.4 (Young et. al, 2020). In addition to re-designing traditional city dashboards, we have also been exploring the potential of multimodal data interfaces, including using 3D environments.

3D geospatial technologies for urban planning and management

While our daily experience of cities is structured in three dimensions, the way we have traditionally made sense of and planned them has been in 2D with the aid of maps, plans and statistical plots. Except for physical scale models, a rarity due to the labour and expense involved in their creation, our understanding of cities and urban form in 3D have been limited to the particular views and vantage points offered by architectural drawings or, more recently, digitally manipulated photomontages. Film and computer animation have introduced duration and movement into visual media, but the experience they conveyed was typically constrained to predetermined paths and itineraries. This began to change with the introduction of real-time rendering and interaction in 3D video games and simulations through the 90s and early 2000s (Whyte, 2002). These limitations are now in the process of being overcome through the development of new interaction technologies such as virtual reality (VR) and augmented reality (AR), new means of organising, storing and sharing spatial data at different scales, such as building information modeling (BIM) and city information modeling (CIM), and the ongoing improvement of methods for generating 3D spatial data using LiDAR scanning and photogrammetry (Valencia et al., 2015). Each of these technologies are spatially-intelligent to the extent that the underlying data can be geo-referenced, can host other data that are geo-referenced (such as the locations of specific objects, infrastructure, and services, or more abstract administrative records that can be linked to particular locations and addresses), and can thus be queried concerning spatial relationships between elements.

These technologies and data have the potential to significantly disrupt existing administrative, planning, architectural, construction and real estate practices. They can enable users to immerse themselves in, explore, interact, query, and experiment with spatially-intelligent virtual environments. Viewed on their own or overlaid on the physical environment they afford a greater understanding of a location, better decisions and policy-making, and improving operational efficiencies (Lock et al., 2019; Young et al., 2017). They create systems similar to Davide Gelernter's 'Mirror Worlds'; computer-generated models in which 'the whole city is visible on a single screen in a dense, live, pulsing, swarming, moving, changing picture' (1991: 30). While affording users the ability to 'dive deeper' into the detail, much like our city dashboards, the overriding value of mirror worlds for Gelernter derived from the overview or 'topsight' they provide; the ability to see the 'big picture' or 'image of the whole' (1991). Through the combination of 3D modeling and real-time sensing enabled through the Internet of Things, this vision is now being realised in the promotion of 'Digital Twin' as means of using 3D models for the monitoring and operational management of buildings and infrastructure in real-time (Dawkins et al., 2018). From a professional perspective, digital twin systems provide responsive means for managing resources, energy consumption and cost in the development of engineered artifacts including buildings. Concerning planning and communication, the use of iconic 3D models which represent an object in the world have long been held to be less abstract and more readily understandable than the 2D maps and charts such as those in our dashboards. At the same time their use can support an epistemically 'naive realism' (Smallman and St John, 2005): the higher the degree of detail they contain, and the more closely they imitate the physical environment through the application of realistic textures and lighting effects (such as shadows that change with the time of day), the more they convey a sense of verisimilitude and the appearance of 'truth' that may in fact be lacking (Kitchin and Dodge, 2002).

These issues are gaining new relevance with the emergence of enhanced 3D spatial media like VR (Virtual Reality) and AR (Augmented Reality) which enable novel means of representing, querying, and interacting with urban data, both within and beyond the fields of planning and urban design (Kitchin et al., 2020). Immersive VR simulates a user's presence in a 3D immersive virtual environment (IVE) using a head-mounted display (HMD) with an embedded stereoscopic screen and other equipment such as earphones and handsets facilitating an embodied interaction within the IVE. The development of VR systems can be traced back to the 1960s (Sutherland, 1968), however, until the mid-2010s use of such systems was experimental and confined to military, research, and high-end industrial contexts due to cumbersome, expensive equipment, limited data, and sub-optimal processing and graphics (Jerald, 2015). Each of these issues has been addressed to some degree, with more affordable, and portable commercial headsets such as the Oculus Rift and HTC Vive. Importantly, VR places the user directly into the IVE by phenomenologically engulfing their senses so as to bestow a sense of immersion and experience of presence when necessary technical and experiential conditions relating to tracking, latency, the field of view and opportunities for interaction are sufficiently met (Curran, 2018). In the context of cities, VR can enable users to explore a 3D simulation of the urban environment at 1:1 scale, and experience and interact with it as if they were present in that scene, at least for controllable variables like spatial layout, visual appearance, ambient noise, and other sensations afforded by peripheral devices such as treadmills or haptic feedback devices. Through networking VR also provides opportunities for such experiences to be shared without requiring the co-presence of participants. Planning and urban design present prime use cases for VR because it enables planners and architects to envision how their proposed designs will fit into the existing environs (their aesthetic properties, impact on sightlines and overshadowing), simulate their relationship to various phenomena (internal energy performance or external pedestrian movements), determine their likely consequences (impact on local demographics, transportation, and economics) and iterate their designs in response (Fisher and Unwin 2002; Kitchin et al, 2019; Portman et al., 2015).

AR and mixed realities provide a different kind of experience by integrating digital content with the user's actual environment so that they are able to observe and interact with both simultaneously. Originally designed to help factory workers assemble complex by overlaying blueprints and instructions (Caudell and Mizell, 1992), AR can now be used to enable collaborative by allowing several planners to view and interact with the same 3D model concurrently without compromising their ability to communicate face-to-face. It can also be used in-situ, on a construction site for example, as a means of validating the design and verifying the construction process. The Pokemon Go phenomenon of 2016 also demonstrated the viability of AR for use by citizens on their smartphones as they move through the city. By using their smartphone's GPS functionality while exploring the city they revealed location-based data in the form of collectible digital creatures, which could then be superimposed on either a stylised environment or the 'real world' as seen through the smartphone's camera. That data might instead be interesting tourist information linked to a monument, planning files associated with a

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particular building, or the locations of utility assets otherwise hidden beneath the city streets, indeed any data that can be spatially referenced to the landscape and represented by a text, image or 3D overlay. In this way, AR exhibits a great deal of flexibility in terms of potential contexts for use and range of applications. As a medium AR is less demanding than VR in terms of its physical requirements for interaction and its monopolisation of the user's sensorium. It also therefore has far greater potential for achieving ubiquity in public space. This in turn may have far-reaching consequences for the way we perceive our environment and interact in public space as suggested by designer Keiichi Matsuda's concept film *Hyper-Reality* (2016).

Enabling these experiences will require new data infrastructures. For the built environment a BIM is a 3D model of the physical and functional aspects of a building or facility which has additional information attached such as details of components, temporal data for construction and installation, and their overall cost (Crotty, 2011). More than a simple visualisation tool, BIM enables the full build cycle of a project to be viewed and queried within one model, reducing the need to coordinate and search hundreds of separate plans, sections and elevations, which can instead be extracted directly from the BIM. It allows users to dynamically update and recalculate scheduling and quantities of materials with changes in design or specifications, and to track supplier details and automatically generate orders for materials. Further, a BIM can be shared across multiple project partners, enabling closer collaboration through the alignment and tracking of complex workflows. After construction, BIM can then be used to coordinate on-going facility maintenance. BIM has become widespread across the urban development sector for managing large construction projects because it enhances project intelligence and management, streamlines processes and produces significant cost savings. For this reason, practitioners emphasise that, beyond its instantiation in any 3D model, BIM is a process (Azhar, 2011).

CIM seeks to extend the vision of BIM byond buildings, facilities, and infrastructure to the city scale (Thompson et al., 2016). While it would be advantageous to link BIMs together to form a CIM, in reality very few parts of a city as yet have an associated BIMs. There are also significant challenges in the integration, management, and visualisation of detailed BIM data at the urban scale. A putative standard for CIM exists in the form of the OGC open standard for 3D city models CityGML[4]. While the standard has gained a highly engaged academic audience concentrated in mainland Europe, wider adoption has been slow. As a result, relatively few CityGML models are being actively used and maintained on an operational basis. One reason has been limited interoperability with other more widely adopted 3D data formats and associated modeling and visualisation applications (Biljecki and Arroyo Ohori, 2015). Another has been the limited support and documentation available for extending the existing CityGML schema to accommodate the development of new applications (Biljecki et al., 2018). Assessments of the standard's

[4]https://www.ogc.org/standards/citygml

performance in Singapore's flagship project Virtual Singapore (Soon and Koo, 2017), combined with responses to the planned release of CityGML 3.0, are likely to have a significant impact on determining its future adoption.

Instead of waiting for standards to match up with the needs of developers and urban authorities, many prototype CIMs are being pieced together from a variety of existing and more highly generalised data sources: layering infrastructure and land-use information, administrative and statistical indicator data, and real-time operational data onto the 3D model. In this way the CIM seeks to act as a 3D spatial data infrastructure to be used for city-wide asset management, examining the spatial relationships between phenomena, and running simulations to determine the behaviour of a range of urban phenomena under different conditions. In essence, CIM seeks to provide an integrated city operating system, distributing urban intelligence across places, sectors, and infrastructures, in order to enable informed decision-making as to how a city is managed in the here-and-now and planned for the future (Marvin and Luque-Ayala, 2017).

Thus far, CIMs are in the prototype phase. Several universities have developed working platforms: Vilo by the Centre for Advanced Spatial Analysis at University College London; CIVAL at Future Cities Laboratory at ETH Zürich; Digital Campus Innovation by Carleton Immersive Media Studio at Carleton University; RAISE project by the Design Lab at the Queensland University of Technology; VGN by Northumbria University; VirtualOulu by the Centre for Ubiquitous Computing at the University of Oulu. Meanwhile, companies such as Cityzenith, VuCity and Dassault Systèmes, partners in Virtual Singapore, have developed nascent commercial products. Still others like A-VR, RealSim, SmarterBetterCities, CyberCity3D, and virtualcitySYSTEMS have been exploring different use cases and applications or developing supporting data and services (see Figure 6.5). Existing CIMs typically work in a desktop environment, and only in a few cases with immersive VR/AR or on mobile devices. The 3D models they incorporate can be derived by the import of existing CAD files, extrusion from 2D building footprints, procedural generation, digitising from stereoscopic images, or conversion from LiDAR or aerial photogrammetry. The models are generally placed on top of map tiles or aerial photographs, though digital terrain models of varying detail and quality may also be used to provide topographic context.

The functionality available on each platform varies. Most adopt a view from above with interactive navigation achieved with a rotating and panning virtual camera similar to those used in 3D modeling and visualisation. Some platforms also providing the kinds of first-person views encountered in computer games with ground movement, flying or teleportation. Some platforms include simulations relating to sunlight, shadows, sightlines, airflow and water physics, people and traffic movements. Some platforms enable users to query the attributes of objects such as building and associated planning information. It may also be possible to toggle different layers of objects and information such as trees and street furniture and to import new models representing planned buildings and infrastructure. In other cases, geographic data can be imported and visualised and may include support for animated views of dynamic real-time data.

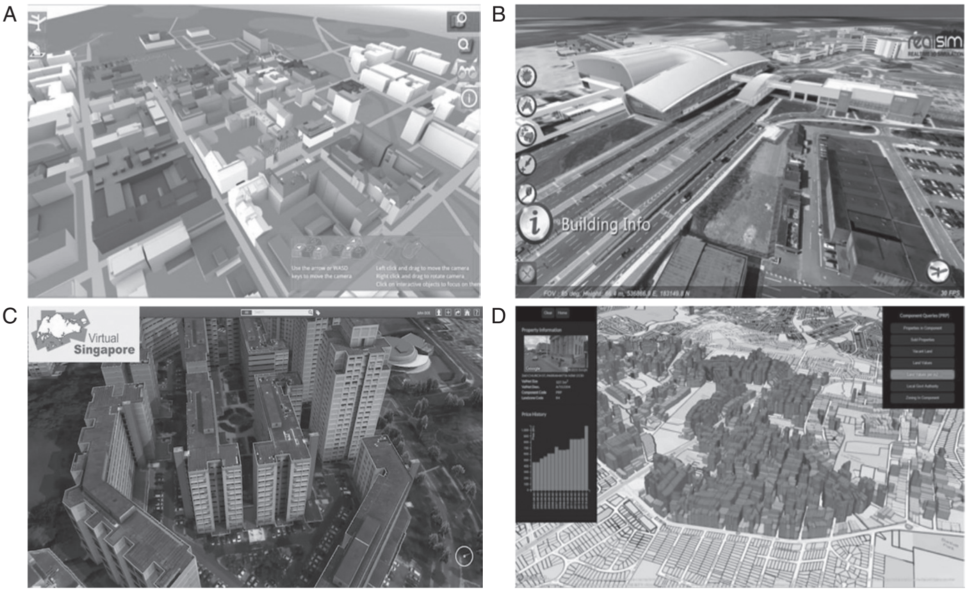

Figure 6.5 Example CIMs

A: VirtualOulu (image from https://ubicomp.oulu.fi/infrastructure-virtualoulu/); B: RealSim (image from https://realsim.ie/); C: Virtual Singapore (image from https://www.nrf.gov.sg/programmes/virtual-singapore); D: RAISE (image from www.research.qut.edu.au) Taken by the authors in 2018

Refiguring the dublin city dashboard in 3D

We have been developing our 3D platform for the Dublin Dashboard (see Figure 6.6). Taking planning as our case study, we are interested in the extent to which 3D visual analytics might provide useful tools for planners at all stages of planning work (e.g., creating strategic, long term plans; public consultation; evaluating planning applications; enforcement). To that end, we have been building desktop, VR (Oculus Rift & HTC Vive), and AR (Microsoft HoloLens) applications. Like other such platforms, we have added tools that enable features to be queried (e.g., clicking on a building to pull up its planning file), new buildings to be added to the landscape, and visualisations of the effects of shadows and the impact of rising water levels. We are also examining ways to import a suite of georeferenced data to create a kind of 3D GIS, and to be able to explore the temporal aspects of such data to show change over time. Here, we are particularly interested in utilising the third dimension to create a new dynamic form of existing kinds of geographic data landscapes or 'datascapes' (Amoroso, 2010). Where the 2D map limits the display of layered data to a single layer at a time due to occlusion, and confines data relating to a specific place to a point or polygon, the 3D medium enables multiple layers and dimensions of data to be viewed simultaneously. In a real-time 3D environment, the represented landscape becomes the medium for the display of data, and that data in

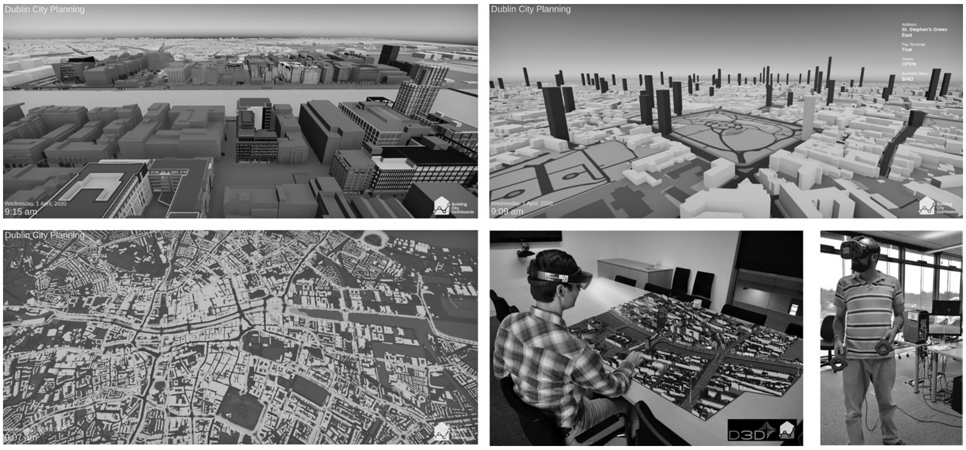

Figure 6.6 Dublin 3D dashboard

Top left: Dublin Docklands in 3D; Top right: Dublin bike scheme real-time visualisation; Bottom left: Dublin air quality monitoring visualisation; Bottom right: Users with Microsoft Hololens mixed reality (interaction concept image) and HTC Vive virtual reality. Created by the authors

turn forms a new synthetic landscape. Areas defined by geographic boundaries become volumes, lines describing paths become walls, and points become towers, each of which can be subdivided, or can incorporate or provide the support for newly derived data and their visualisation (e.g. points-towers that describe not only a magnitude but a standard deviation). In this sense, in VR the abstraction from territory to map becomes partially elided through the creation of virtual landscapes (Dodge and Kitchin, 2000), though AR can also operate in a Borgesian way, with the map directly draped on the territory. As such, 3D spatial media renderings open interesting questions concerning the mapping of cities that require further philosophical thought (Kitchin and Dodge, 2002).

Like city dashboards, 3D geospatial tools are not without their challenges. At a basic level, it will be difficult to implement comprehensive models in many city jurisdictions in the short-to-medium term unless there are significant improvements in data availability and quality. Moreover, the tools to produce and combine high quality, interactive media with geographic data are still lacking. While it is relatively straightforward to display a 3D model, importing other geospatial data and adding visual analytics into these models is more complex – in the main because the games engines used to facilitate real-time multimodal interaction through VR and AR are not designed to act like GISs (in fact they typically make different assumptions about the choice of coordinate reference system and the degree of precision required for calculating spatial location). Likewise, 3D geospatial applications will require critical attention as to their production and epistemology and the social, political and economic effects of their deployment. As with mapping in general and other spatial media, 3D geospatial technologies present the world as a systematic, ordered, commonsensical form of knowledge, made even more powerful because their visual form replicates how the world appears (3D), rather than being abstracted into 2D. Moreover, they enable us to project the 'present future' (Adam 2004), which is to imagine the city as it might become by placing potential new buildings and infrastructure into the models, which then become the blueprints for creating that future. Yet, as Rose et al. (2014) have argued, 3D architectural renderings and city images are far from apolitical. They are in fact laden with politics and ideology designed to promote certain urban visions. Further, 3D geospatial technologies generally deal with location, geo-referenced factual data, and urban form, and largely ignore the metaphysical aspects of human life, and the role of politics, ideology, social structures, capital, and culture in shaping cities (Kitchin, 2014b). The danger is then, that if used in isolation, they decontextualise a city from its history, its political economy, its wider interconnections and interdependencies, the wider set of social, economic and environmental relations, and the everyday experiences of people living in the city. As CIMs gain wider adoption and begin to have tangible impacts on the planning and management of cities, citizens may regret the epistemic and ontological commitments embodied in the programming of their front-facing functionality and the schemas structuring their underlying data if they go unexamined and unchallenged.

As Dawkins (2017) argues, while many mirror-world-like platforms and applications are aimed at professional users in the fields of architecture, engineering, construction, urban planning, and asset and operations management, such systems are not inherently limited to these professional groups. As with participatory and critical GIS, and counter-mapping and citizen science initiatives (Elwood, 2006; Haklay, 2013; Peluso, 1995), 3D geospatial technologies can be used reflexively and in conjunction with other forms of knowledge and praxes to provide a more situated view and can be appropriated by individuals and communities in pursuit of their ends. He discusses ViLo, a 3D spatial environment of London created by CASA at University College London, which enables the exploration of dynamic data visualisations of various urban events as they occur in real-time (such as the movement of buses and trains, the availability of bikes at bike-share stations, sensor readings, and social media postings at particular locations). Used with AR the system, ViLo could enable the discovery of and interaction with data and other digitally mediated aspects of the city. In relation to the user's actual position in the city, spatial relationships that seem abstract on a two-dimensional map would become relatable with regard to the scale and orientation of the human body; and digital artifacts like data visualisations could be intuitively incorporated into their user's own spatial and sensory field of reference through their augmented field of view. Unlike the closed 'dataspaces' of control rooms, that system presently operates on entirely publicly accessible and open data and could form the basis of collaborative workspaces in which citizens could explore and formulate plans for their own local environments. With support, instruction, and realistic expectations, such systems can be pieced together from free-to-use and open-source software. In this way systems like ViLo point the way and contribute to the opening of a space of collaborative digital agency and participation.

Conclusion

City dashboards are becoming increasingly popular as a means of monitoring and presenting recurrent and real-time data about various aspects of cities and using the information to make sense of and manage services and infrastructures. With their use of various visual analytics, they constitute a very salient example of applied data analysis for urban planning and management. That said, they are not without critique and our research on the Building City Dashboards project is seeking to tackle the six issues identified by Kitchin and McArdle (2017) relating to epistemology, scope and access to data, data quality and ecological fallacies, usability and data literacy, appropriate application, and socially responsible design and use. In particular, there is still much work to be done to improve user experiences and to formulate general design principles for communicating indicator data, time-series data, and real-time data (Stehle and Kitchin, 2020; Young and Kitchin, 2020) that are common for other forms of visualisations such as maps. Particularly, there is a need for approaches that are guided by user feedback and requirements and which tries to cater for a range of potential users (Young et al., 2020). There is also much scope for moving beyond visual analytics to include a wider set of data analytics, statistical modeling, and generate and evaluate predictions, simulations, and optimisations, which is another core aspect of our research.

It is also the case that emerging 3D geospatial technologies are providing opportunities to create new ways of visualising cities and their associated data. Their representative qualities (as 3D rather than 2D), immersive nature, and interactive spatial intelligence are starting to generate a diverse set of applications concerning planning, city operations management, asset management, architecture, construction, policy formulation, autonomous vehicles, citizen and tourist applications, and urban play and games. However, immersive VR, AR, CIM, and other technologies reliant on 3D data, such as autonomous cars, are still a few years from reaching the tipping point where their use becomes mainstream. In part, this is because the technology and its application to domains such as planning are still evolving, with affordable headsets only recently becoming available and use cases still in the experimental rather than the commercial phase. In part, this is because development platforms are yet to emerge that satisfactorily combine the real-time rendering capabilities of game engines with the GIS-like ability to store and handle geospatial data in native formats and coordinate systems with the requisite spatial precision. It is also still relatively difficult to find publicly accessible 3D city models that are sufficiently highly detailed to meet user expectations while maintaining the kinds of cross-application compatibility required by developers. That said, several national mapping agencies have started to generate new national 3D data sets derived from LiDAR data, and there are data with the variable quality available through OpenStreetMap and commercial vendors. Large corporations, such as Google and Nokia, have created or are in the process of creating global 3D datasets for a variety of projected uses, including autonomous vehicles, though these are not publicly available. Besides, there is an increasing number of project-based 3D models generated for specific purposes (e.g., asset management and urban development) by companies and city administrations. The quality, veracity, and fidelity of these data are improving markedly, especially for high-value markets such as large-scale construction.

In short, while there are still a set of fundamental and technical challenges to be overcome and critique to be addressed, city dashboards and 3D geospatial technologies have the potential to provide a set of tools for urban managers *and* citizens for making sense of, planning and managing cities, and to do so increasingly in real-time. Whether these will constitute disruptive innovations that will radically transform the praxes of domains such as planning, only time will tell.

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