Chapter 2
Building 3D and XR City Systems on Multi-Platform Devices

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ABSTRACT

In this chapter, the authors detail how six commercial products have sought to provide 3D spatial media solutions for the planning domain, and set out their own approach to developing an interactive, multi-platform city information model (CIM) for desktop/WebGL (on a PC), VR (HTC Vive), and MR (Microsoft HoloLens) for Dublin informed by user requirements elicited through interviews with professional urban planners. They demonstrate how a Unity game engine solution can be used to build and manage a multi-platform CIM project from initial stage to the final build. They discuss issues concerning the handling geographic data, data integration, UI development, multi-platform support, interaction types (controllers, gestures, etc.), and potential application. They present core interactive simulations, including shadow analysis, flood resilience, visibility analysis, importing building models, and run-time modeling tool, which are crucial for city information modeling.

INTRODUCTION

For three decades, the case has been made for utilizing a variety of 3D spatial media for understanding and modelling urban environments, including 3D GIS, virtual reality, and city information models. In the 1990s, several projects had started to develop nascent 3D virtual models of cities. For example, Kirby et al. (1996) created a 3D GIS model of Adelaide, Australia; Bourdakis (1997) used computer-aided design to create a geometric, textured model of Bath, England, which covered several square kilometers;

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Chan et al. (1998) developed an urban simulation system for Los Angeles that combined GIS and VR; and Batty et al. (2000) produced a 3D model of Virtual London using CAD, GIS and VRML. Despite significant advances in 3D spatial technologies and the creation of 3D spatial datasets since the 1990s, as yet 3D spatial media have still not become mainstreamed in the planning profession. Moreover, there is little consensus as to how best develop such 3D spatial media in terms of approach and technologies, or their desired functionality Kitchin et al. (2021).

The objective of the chapter is to detail present approaches to 3D spatial media, assessing how six commercial products have sought to provide solutions for the planning domain and their functionality, and to set out our own approach to developing an interactive, multi-platform City Information Model (CIM), informed by user requirements elicited through interviews with professional urban planners. The development of our own CIM platform was to examine the potential to create a universal, multiplatform (for desktop/WebGL, VR (HTC Vive) and MR (Microsoft HoloLens), open-source solution using games engine approach (Unity) with extensive functionality that matches planners' expectations and needs, and to identify issues with such an approach and workable solutions. The platform needed to perform a number of tasks of interest to professional planners, such as placing new proposed buildings in the landscape, revealing viewsheds, sunlight/shadow analysis, run flooding simulations, and to display a variety of planning and property data (e.g., land zoning, development plans, planning permissions, property prices, architectural and heritage status) and some real-time data related to environment and transport.

BACKGROUND

Studies have utilized and assessed a series of increasingly sophisticated technologies for visualizing and simulation city landscapes, including: Computer-Aided Design (CAD) (Al-Kodmany, 2002), 3D modeling packages (Schreyer, 2013), 3D Geographic Information Systems (3D GIS) (Koninger & Bartel, 1998; Gu et al., 2011), Virtual Reality (VR) (Doyle et al., 1998; Salter et al., 2009; Portman et al., 2015), Mixed Reality (MR) (Guo et al. 2008; Ghadirian & Bishop 2008), and Building Information Modeling (BIM) (Crotty, 2011). Most recently, research has focused on developing nascent City Information Modelling (CIM) systems that utilize a number of these technologies such as 3D GIS, VR and MR, draw together and interlink at a city-scale a range of 3D landscape and building data, as well as other administrative and operational spatial data, and enable their exploration using a variety of query and simulation tools (Thompson et al., 2016; Stojanovski, 2018).

For those developing and promoting 3D spatial media the hope is that they will become an integral part of urban planning and development practice supporting better decision-making. They argue that 3D spatial media have the potential to improve significantly communication and comprehension by providing spatial representations that are closer to common perceptual experiences than maps, plans, and perspective drawings, and can be viewed from different perspectives and explored in an immersive way (Doyle et al., 1998; Pietsch, 2000; Paar, 2006; Shiratuddin & Thabet, 2011). As Gordon and Manosevitch (2010) note, immersed users potentially experience the streetscape, not the idea of the streetscape as conveyed by traditional maps and plans. This phenomenological experience increases with higher levels of detail and more photorealistic rendering of the architecture and terrain (Appleton & Lovett, 2005; Franklin et al., 2006). Consequently, a recurrent case has been made for the use of 3D spatial media to enrich public understanding of prospective urban design in public consultation, facilitate participatory planning, and help democratize the planning process (Doyle et al., 1998; Ghadirian & Bishop, 2008;

Wissen, 2011). From an urban design perspective, 3D spatial media offer opportunities to quickly and efficiently experiment, practice, simulate and assess design interventions, enabling rapid and iterative prototyping in a cost-effective way (Portman et al., 2015).

Yet, despite significant research and the development of numerous prototype and commercial systems, the applied use of technologies such as 3D GIS, VR/AR, and CIM have yet to be mainstreamed across the planning profession. In the 1990s and early 2000s, the technology was experimental, costly, bulky, underpowered, and provided a poor user experience: lacking realism, interactivity, and the required functionality (Drettakis et al., 2007). 3D data was difficult to source, suffered from poor spatial resolution, and was challenging to integrate with other spatial data from different formats and sources (Franklin et al., 2006). By the late 2010s, the performance and cost issues have been largely addressed. However, there are still issues with sourcing 3D data, integrating and linking data within systems, and providing a suite of interactive modelling and simulation tools that planners desire (Thompson et al., 2016). Generally, games engines used to underpin product development are not designed to act as 3D GISs, having a different coordinate system (x, z, y and true 0,0 origin, rather than x, y, z and latitude/longitude). 3D GISs do not possess the graphics rendering capabilities and developer tools of games engines.

XR (Extended Reality) is the combination of real and virtual environments where the interaction between human and machine is generated by wearables or computer technology. In other words, XR is an umbrella term that captures all AR, VR and MR together (Mann et al., 2018). In Virtual reality (VR) the user is immersed in a computer-generated interactive virtual world (Kim et al., 2000; Onyesolu, 2009a; Onyesolu & Akpado, 2009b). Augmented reality (AR) consists of overlaying computer-generated information on the real world, achieved by projection on clear glasses (Silva et al., 2003). In Mixed reality (MR) virtual objects are not just overlaid on the real world like a layer but can be placed behind real objects. This form of mixed reality can be considered as an advanced form of AR. Mixed reality is the next stage of holographic interaction in multi-mediated reality (Mann et al., 2018).

Our study sought to explore ways of over-coming the limitations of combining a games engine with 3D GIS to create a multi-platform CIM for Dublin that could handle and integrate a number of spatial data sources, including real-time data, and possessed a suite of tools that would have utility for the planning profession. To that end, our work was guided by an evaluation of the functionality of existing commercial systems and requirements interviews with 14 senior professional planners working in local government planning departments in Ireland (Kitchin et al., 2021). Our aim was not to produce a commercial product, however, but to use the process of building a functioning CIM as a means to examine viable solutions for imbuing games engines, in our case Unity, with some of the functionality of 3D GIS and addressing known issues in creating 3D spatial media.

CONTEXT FOR DEVELOPING A MULTI-PLATFORM 3D AND XR SOLUTION FOR CITY PLANNING

Existing 3D City Systems

A number of commercial 3D planning tools are presently available that claim to assist local authorities in advanced urban design, development, and managerial processes. Furthermore, there is a movement at present to augment these tools and present their functionalities via virtual (VR) and mixed reality (MR) technology. Many 3D city systems are focus on achieving high levels of 3D photorealism, whereas others are concentrating on city data visualization, integrating building information models (BIMs), or providing specific design interaction tools for city planners and urban management. We selected six 3D city systems to evaluate, each of which is relatively sophisticated and successful in displaying a 3D city model and associated spatial and temporal data: RealSim, Sitowise, VU.CITY, Skyline, Cityzenith and Virtual Singapore (see Figure 1). Our initial selection was made in 2017 at the start of our project and each of the systems has made big strides forwards in terms of the tools, functionality and user interface and experience in the intervening years. RealSim is an Irish company specializing in 3D real-time simulations that uses environment information models (that combine 3D mapping, architectural and engineering information) to create detailed (LOD 2 or 3 with some texturing or photorealism) virtual reality landscapes in which planning related simulations can be performed. Sitowise is a Nordic company specializing in smart city solutions. One of its products is Aura, a virtual 3D environment for creating and managing an urban digital twin (including GIS and BIM data), and visualizing and simulating built environment data, including material textures. VU.CITY, a UK-based company, produces 3D models at 15cm accuracy of city landscapes that allows collaborative exploration and the running of various planning-related simulations. Skyline Software Systems is a US-based company that specializes in 3D earth visualization and services. Its TerraExplorer application is a 3D GIS digital twin that enables the management, visualization and analysis of various 3D data, imagery and other spatial data. Smart World Pro by Cityzenith is likewise a 3D platform for visualizing and analyzing digital twin data. Unlike the other approaches examined, Virtual Singapore is a government initiative to produce a dynamic, collaborative 3D city model of the nation that enables asset management, modelling and simulation, and planning and decision-making, and research and development.

We categorised the functionalities and tools currently provided by these six 3D city systems in relation to city planning and urban data visualization as available in 2017 (see Table 1). What is clear is that no system provided a full suite of potential useful functionality, as discussed by our interviewees (see next section) or provides a comprehensive multiplatform solution. In part, this is because systems are targeting different aspects of the planning system rather than the full suite of planning tasks, are concentrating on particular platform solutions, or the functionality is difficult to produce either technically or because of limitations in data supply and quality.

Figure 1. Existing city systems: (a) RealSim, (b) Aura by Sitowise, (c) VU.CITY, (d) TerraExplorer by Skyline, (e) Cityzenith, (f) Virtual Singapore

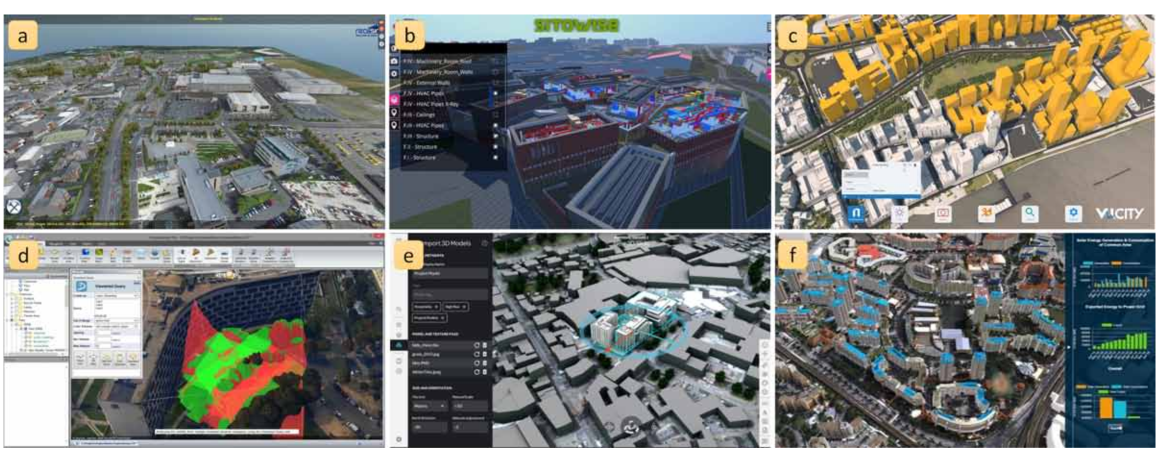


Table 1. Core feature comparison of six commercial city 3D spatial media

		Building City Dashboards	RealSim	Virtual Singapore	VU.CITY	Smart World Pro	Skyline	Sitowise
Platform	Desktop	Y	Y	Y	Y	Y	Y	Y
	VR	Y	Y	N	Y	N	N	Y
	MR	Y	N	N	N	N	N	Y
View	First person view	Y	Y	Y	Y	N	Y	Y
	Bird's eye view	Y	Y	Y	Y	Y	Y	Y
	Inside building examination	N	Y	Y	N	Y	Y	N
3D Environment	Show/hide elements	Y	Y	Y	Y	N	N	Y
	Sunlight	Y	Y	N	Y	Y	N	N
	Water physics	Y	Y	Y	Y	N	N	N
	Animated trees	N	Y	N	N	N	N	Y
	Crowd	N	N	N	N	N	N	Y
	Traffic	N	Y	N	N	N	N	Y
	Underground city infrastructure	N	N	N	Y	N	Y	Y
Simulations	Flood resilience	Y	N	N	N	N	N	Y
	Visibility analysis	Y	N	N	N	N	Y	N
	Shadow analysis	Y	Y	Y	Y	Y	Y	Y
	Lighting simulation	Y	N	N	N	N	N	Y
	Managing noise pollution	N	N	N	N	N	Y	Y
Data	GIS/Spatial	Y	Y	Y	Y	Y	Y	Y
	Real-time	Y	Y	Y	Y	Y	N	N
	Traffic cameras	N	N	N	Y	Y	N	Y
	Lidar	N	N	N	N	N	Y	N
Model information	BIM	N	Y	Y	N	Y	N	Y
	CIM	Y	N	Y	Y	Y	Y	N
	Zoning info	Y	Y	Y	Y	N	N	N
	Semantic information	N	N	Y	N	N	Y	Y
	Point and click height information	N	Y	Y	Y	N	N	N
	Highlighting buildings	Y	Y	Y	Y	Y	Y	Y
Planning tools	Building markers	N	Y	N	N	N	Y	Y
	3D manipulation	Y	Y	N	N	Y	N	Y
	Import 3D models	Y	Y	N	Y	Y	N	Y
	City planning timeline	Y (CONCEPT)	N	N	Y	N	N	Y
	TOTAL	20	20	15	19	13	14	23

Information that is attributed to a 3D model is a representation of key concepts and their relationships, constraints, rules, and operations regarding specific data semantics of a chosen discourse. In this context, we specified six types of information models including building information models (BIMs), city information models (CIMs), city zoning information, point and click height information, highlighting specific buildings, and semantic information. While some 3D tools choose to focus on either Building Information Modeling (BIM) (RealSim, Sitowise) or City Information Modeling (CIM) oriented (VU.CITY, Skyline), others attempt to do both (Virtual Singapore, Smart World Pro).

Navigation in a virtual environment is important for users to explore simulated space. We therefore investigated the most used navigation modes; including first person, bird's eye view, and internal building structure explorations (a first-person view for inspecting BIM models). A bird's eye view is currently supported by all 3D systems. Internal building examination was accessible in 4 of 7 solutions. 3D cities are often built for larger-scale observations, where the camera is located to enable whole city perspectives, or for exploration specific buildings in the model. 3D navigation was crucial to reach the street level and one solution did not support this at all (Smart World Pro).

Interactive virtual environments can be enhanced by adding static ecological elements. When building 3D urban models, 3D environments can be supplemented with animated milieu, including trees and parks, pedestrians and crowds, traffic, and so on. Having the option to switch ecological elements on and off is crucial for data visualization purposes, where they may obscure GIS data layers. Furthermore, hiding ecological elements – as a feature – was only absent in Smart World Pro and Skyline. This feature also helped the user to view underground infrastructures, which were provided for VU.CITY, Skyline, and Sitowise. Other ecological features included sunlight, water physics, and animated trees. Making 3D cities come alive is not an easy task and some 3D tools did not offer these features, such as simulated traffic and crowds.

3D planning tools should facilitate planners in making informed decisions based on the available data. 3D tools should, therefore, improve the decision-making process by including the relevant tools for various urban planning applications. Our research localized four main features and tools that were implemented in each of the 3D tool analyzed. The first feature was based on using markers to constrain the building outline and generate a mesh between those points (starting from flat polygon). This approach was used in RealSim, Sitowise and Skyline. The second feature was interacting with 3D objects, and manipulating their position, rotation and scale. The third feature was the ability to add 3D objects with or without textures created in external 3D software packages; such those created in CAD and other modelling software. This feature allows city planners to use their own 3D models. This model importing tool was available in Virtual Singapore and Skyline. By combining multiple proposed building models a timeline slider could be manipulated for visualizing future planning and development scenarios. This was based upon assigning each scenario to one point in time and scrubbing through the timeline. By viewing different timeline development simulations, planners can potentially foresee any future problematic construction interactions. Interacting with these features was done so with advanced user interface modules. This feature was provided by two of the systems, VU.CITY and Sitowise.

Displaying and accessing data is a key feature for local authority planners. Data in this context relates to distinct pieces of information, usually formatted in a specific way. Generally, each 3D tool supported GIS data standards. However, real-time city data was not supported by Sitowise and Skyline. Platform relates to the basic hardware or software on which a 3D tool runs. In this study, desktop PC, VR, and MR fall into this category; where each of the evaluated systems can be presented on platforms that facilitate different modalities of interaction. Through the analysis of current marketing materials and open-source demo versions of their software, it was observed that of the 3D urban planning systems assessed, the standard application platform was desktop PC (available for all solutions). The use of VR was supported by RealSim, VU.CITY and Sitowise only. MR experiences was limited to Sitowise. Access to multiplatform solutions (PC, VR, MR) by planners may be a key feature in the future, as emergent immersive solutions may help to reach wider audiences. Therefore, there is potentially a market for applications to be more flexible with regards to the platform. In this way, immersive and engaging experiences can be harnessed to facilitate preplanning and co-design planning processes.

User Requirements

In addition to evaluating existing systems, to guide our own development and research we interviewed 14 experienced planners (Senior Executive Planner (n = 5), Senior Planner (n = 4), Executive Planner (n = 3), a Senior Architect (n = 1), and a technical staff member (n = 1)) who had worked across all aspects of local government planning (e.g., strategic planning, development management, compliance, and enforcement). Their knowledge of 3D approaches to planning and the various products available was broad. However, their applied experience of using 3D spatial media was constrained and the cohort admitted having very little hands-on experience of using such tools in their day-to-day work. They noted that a small number of colleagues might produce bespoke 3D models as part of their work, but this depended on the project and skills of particular team members. The use of 3D spatial media was not generally seen as a constituent part of mainstream practice for LA planners and their current use largely focused on the visual aspects of communication and assessment of design plans. However, while the use of 3D spatial media in planning departments was relatively limited, all the interviewees recognized their potential to contribute to the planning system and to their day-to-day work with respect to strategic visioning, public consultation, pre-planning processes, development management, application assessment, compliance, and enforcement.

When consulted as to what specific features they would desire in 3D spatial media for planning our interviewees were rather hesitant and speculative. In the main, they anticipated using any system as a visualization and scenario planning tool to test different scenarios and assess proposed developments and its potential effects upon the existing landscape prior to any significant investment. Or they imagined using a system as a 3D GIS that would enable different data layers – existing plans, development, housing and heritage information, utility infrastructure, social/economic variables, environmental factors – to be visualized and queried. They were most interested in a desktop platform to fit their existing working arrangements and technical competences, rather than a headset-based solution, but would welcome the opportunity to test the affordances of an immersive experience. Across the 14 interviewees the suite of functionality and features detailed (in Table 1) were discussed. Using the interviews as a guide we then designed our own multiplatform system to examine the viability and issues in creating a working CIM and the affordances created through different platforms (desktop, VR, MR). To provide additional context we also explored the approach and functionality of existing 3D city systems.

The BCD Project

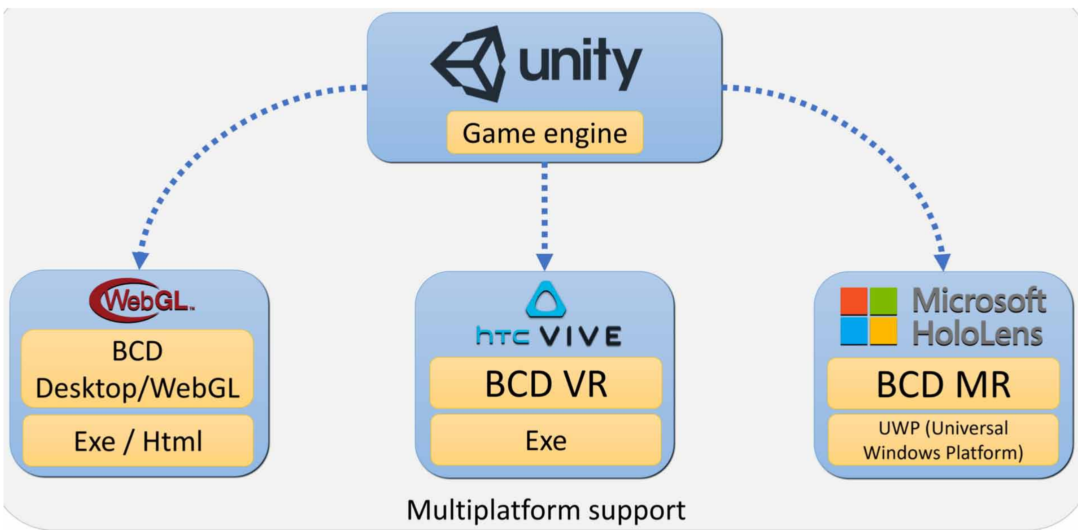
Initial Stage – Feedback from City Planners and Development Direction

Based on the evaluation of existing systems and the feedback from our interviews with planners, the Building City Dashboards (BCD) project mapped out a potential multiplatform solution (Figure 2) using the Unity game engine as the core development environment.

Unity3D software can run on multiple platforms with online and offline modes. In our case, we focused on the Windows platform only where the development process was performed. Unity3D also allows users to publish the developed games on other platforms (especially XR platforms with full support) and provides a variety of functions and module libraries for multi specifications of gaming development (Bae & Kim, 2014). For the BCD project, we had created each system from scratch. The initial stages involved 3D data integration with corresponding attributes, multiplatform UI development – including interaction design and developing other useful features (especially real-time simulations). Most 3D modeling software packages cannot cope with spatial data because of the mapping projection systems used. Unity likewise does not support a real-world coordinate system and there are no transformation tools or libraries for coordinate conversions. We thus had to devise a process for successfully transforming and importing spatial data using ESRI CityEngine, a 3D GIS platform. In addition, the Unity 3D game engine supports very limited input formats (e.g., fbx, sbx and .obj) which focuses on geometry, vertex and faces ordered. Thus, it creates limited interoperability during the conversion process such as loss of semantic and attributes (usually provided in external CSV file) (Buyuksalih et al., 2017).

The project was split up into three categories: BCD Desktop/WebGL, BCD VR and BCD MR to be accessible on different devices (desktop - PC unit; VR – HTC Vive glasses; MR – Microsoft HoloLens glasses). An AR version was not developed because BCD MR is more advanced. Core modules were created in Unity grouped into categories including: UI elements, 3D environment, planning tools, scene components and explorability (navigation modes).

Figure 2. Multi-platform support in Unity with dedicated output file extensions
Sourcing Input Data - Dublin 3D City Model (D3D) and City Layers



The Dublin city model was obtained for research from a Dublin-based private surveying company D3D. The city model compromised two square kilometers of a central area of the city. The model was created in 3D Studio Max. The main buildings were fully 3D models while the rest of the city was created using satellite photos and photogrammetry. The main buildings had real-world textures superimposed in the form of photos previously prepared in Photoshop. Additional data layers were sourced from myplan.ie (a government planning portal), along with other data providers such as the Central Statistics Office and Dublin City Council. These data layers were grouped into five categories: Planning history (architectural heritage, national monuments); development land use (development plan, planning applications); environmental (noise levels, air quality); property prices (price paid register); and Census data (various demographic and housing data).

BCD – Coordinate System for 3D Model and City Layers

The Unity games engine utilizes a different coordinate system to traditional geographic data systems. Whereas geographic data is anchored around a latitude and longitude coordinate system, Unity employs a fixed 0,0 origin, a localized scale, and the main plane of movement is forward/backwards (horizontal) rather than up/down (vertical) as with mapping systems. Consequently, geographic data imported into Unity needs to be rotated and realigned to gain the correct plain of movement, and data layers need to be fused to ensure they share the same local scale and origin point. The initial step then was to establish common coordinates for the 3D model and data layers for use in Unity. This was achieved by importing the model and layers into City Engine, a 3D GIS package, to marry them together, saving as a .fbx file. The next stage of the project was loading the city model into the Unity engine and assign missing textures. Not all textures were imported correctly so they had to be fixed by using shaders in Unity. The peelings with a partially transparent structure, like trees, required the use of additional shaders that were able to render the alpha channel. In addition, to improve the realism of the virtual scene, a realistic animation model of water, sky and sun has been added, which introduces the time of day and night.

BCD - Interactive City Maps

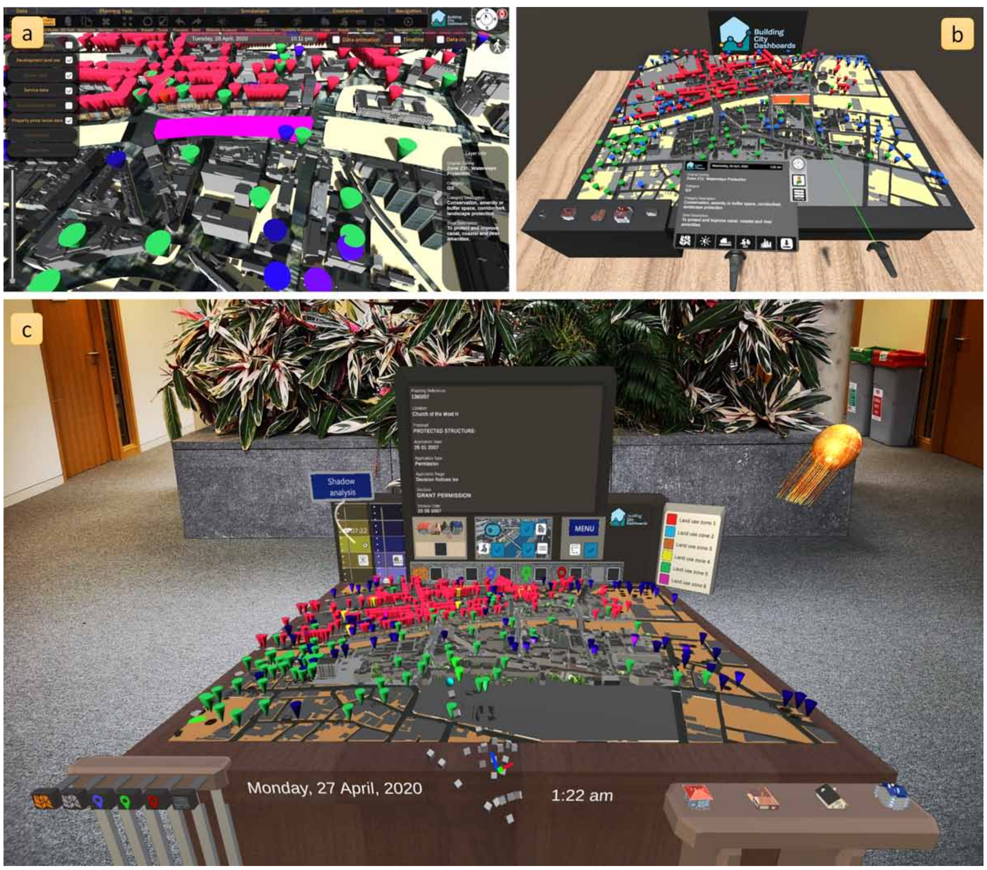
The idea behind city model was to combine the 3D terrain and building model with 3D layers and create the possibility of interacting with the data. After fusing the model and data layers, the next step was to combine the city layers with text data. The city layers contained two types of files - shape files (* .shp) and text data files (* .csv). A CSV reader script was used to read the content of the CSV files. It was necessary to create a class for each layer in order to directly reference a CSV file, with reading the table contents and displaying individual values enabling interactive queries. In the case of adding interaction to the layers that with areal data, no pinpoints were needed. In cases where the data objects were relatively small, for instance the markers for the paid property register, it was necessary to attach the pinpoint in the form of a 3D external object. The last stage in creating interaction was adding a map click detector using the MouseSelectHighlight function. The base interaction created for the BCD VR used Map Click Detector as Vive Input Utility was able to process all standard elements from Unity if they were attached to Canvas with Raycast Target added. In the case of the BCD MR, the Map Click Detector from the standard BCD 3D version could not be used. In this case the IMixedRealityFocusHandler components were used.

BCD - Cross-Platform Interfaces, Interaction Modes and Navigation

It was necessary to develop the UI interface for each BCD project separately. We decided to have three independent projects where the base content was the same (3D model with city layers). Other used UI components had to be dedicated to each platform to ensure optimal operation. For BCD Desktop we used all standard Unity UI elements with some extra packages imported to the project like GILES, real-time clouds, Ciconia Double Shader (for tree transparency), etc. The BCD VR project used the Vive Input Utility package which did not require many changes from our BCD initial desktop version, except from a design perspective. The menu had to be rebuilt and assigned to the left controller but there was one Canvas script to recognize all the previous desktop tools in VR. Based on that, most of the functionalities from BCD Desktop could be transferred directly to VR. It was especially important to transfer simulations.

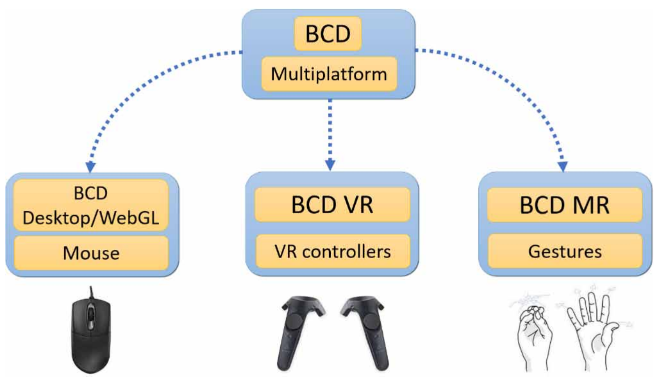
The situation changed with the BCD MR project. All the features of the BCD Desktop did not work in MR and it was necessary to import the Mixed Reality toolkit with all predefined UI components. We replaced all standard UI components by Mixed Reality UI components from the toolkit to make a new interface for BCD MR. The result was we had the same project running across platforms with three user interfaces (Figure 3) and different interaction modes (Figure 4).

Figure 3. Cross platform BCD project UI interfaces, menus and display windows for: (a) desktop version; (b) VR version; (c) MR version



BCD Desktop was designed to meet user requirements in a traditional way. There are no extra haptic devices required to interact with the project. Specific information about data layers such as land-use zones, property price data, monuments service data, planning applications, etc. can be requested through mouse interaction in the PC version. PC screen is the output window where the user can see the results of their own actions. Interaction in VR is very different to a standard PC. In our case, we used HTC Vive rig with two controllers. The main menu was assigned to the left controller while the right controller contained a pointer to perform actions. The BCD VR project contained two scenes – one for a street view where the user had a normal scale and a bird's eye view for a larger city overview. All interactive content from the menu (checkboxes, sliders, etc.) could be activated or deactivated by pressing triggers in the right controller. Before performing any action, a pointer from the right controller had to face the desired tool from the menu. On the top of the right controller, a function to teleport was assigned. There are no interaction controllers for BCD MR. The user can use their own fingers to perform predefined gestures (Air Tap, Tap and Hold, Bloom) and interact with interactable elements from the project like checkboxes, sliders or other elements. On every platform the BCD project lets the user navigate in a different way. In BCD Desktop there is no physical movement and exploration is performed on the PC screen. While BCD VR allowed exploring the Dublin city by physical movement or by virtual teleport BCD MR allows full physical movement and there is no option to teleport.

Figure 4. Cross-platform interaction modes



Each of the three platforms were built in parallel using the Unity editor. Development passed through a number of stages (see Figure 5). The next stage included creating simulations, features and tools for public users and city planners. The last stage was to build a UI interface for desktop, VR and MR and adjust all features to be utilized on each platform. The result was suite of modules and components (see Figure 6). BCD Desktop/VR required one build from Unity and can be launched directly afterwards from an .exe file. BCD MR required one build to UWP (Universal Windows Platform) and the second deployment stage from Visual Studio to Microsoft HoloLens device. To perform deployment to the device-specific settings were applied including: solution configuration, solution platform and attachment.

BCD - Features and Tools for City Planning

The BCD project included a number of core features to facilitate city planning actions: interactive layers, shadow analysis, flood resilience, visibility analysis, and adding buildings (see Table 2).

Visualization in 3D urban planning provides an interactive platform for communicating with the public and utilizing different data layers. The traditional approach in visualization is to demonstrate information and data within a 2D framework (Figure 7a). The 2D layers are complex and only planning professionals can fully manipulate information. Consequently, the potential use of 3D, VR and MR systems in the BCD project has been explored in depth to overcome the limitations of 2D systems.

Figure 5. The BCD project development stages

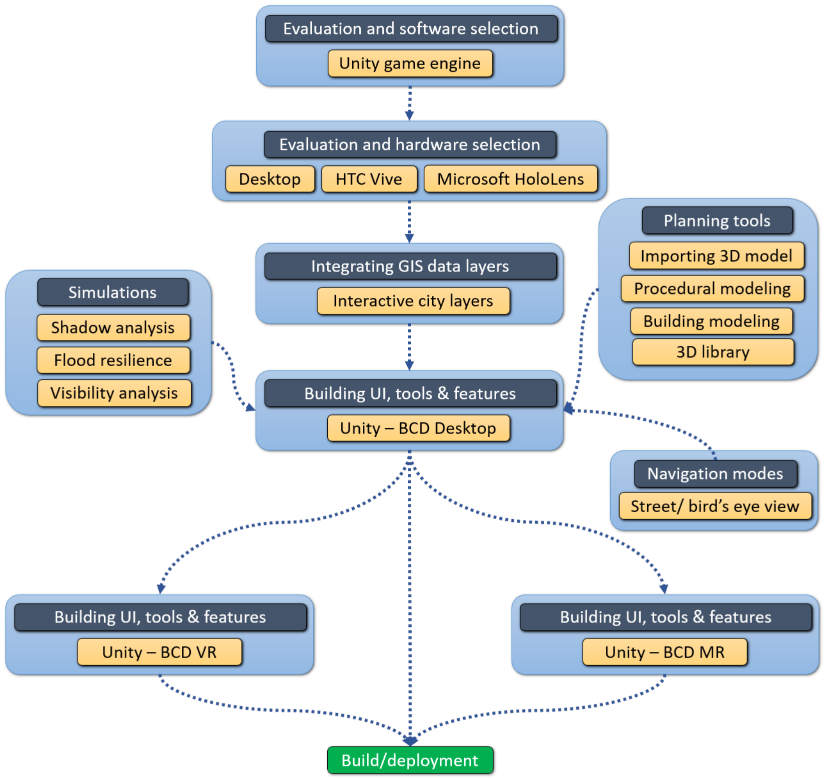


Figure 6. An overview of the BCD project modules and components

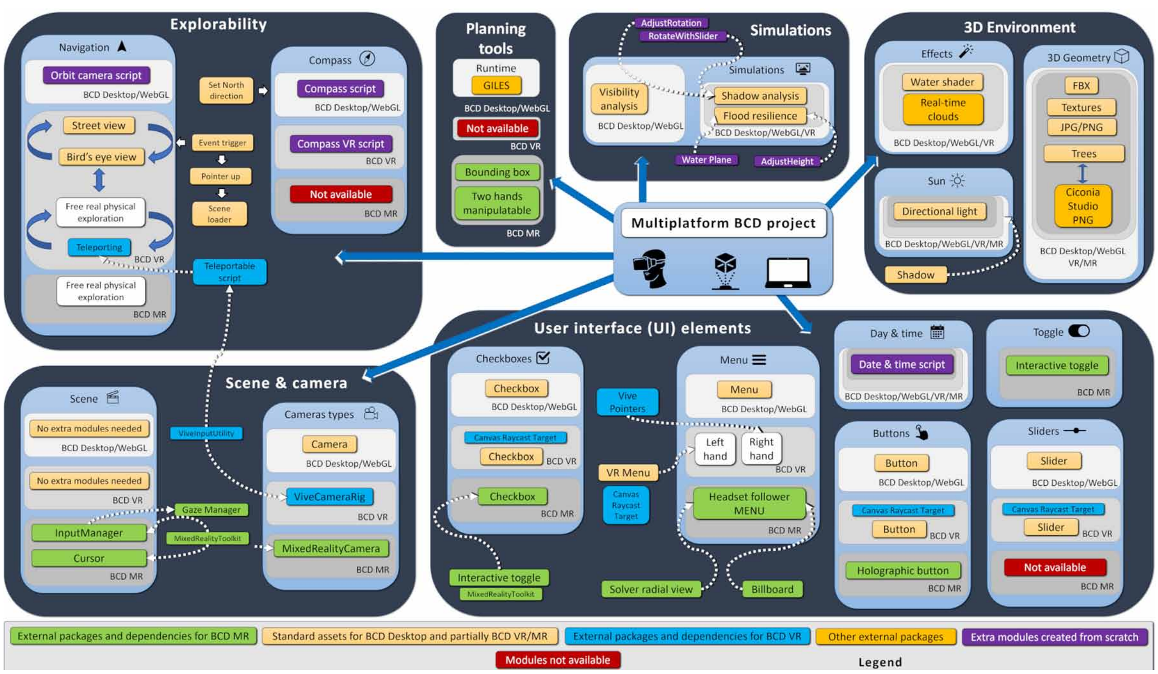


Table 2. Features and tools for city planners available on every platform

Features	BCD Desktop	BCD VR	BCD MR
Shadow analysis	YES	YES	YES
Flood resilience	YES	YES	YES
Visibility analysis	YES	Under development	Under development
Runtime 3D tool – basic shapes	YES	-	-
Procedural 3D modeling tool	YES	YES	-
Importing 3D objects	YES	Under development	Under development
Building library	-	-	YES
Interactive city layers	YES	YES	YES

Figure 7. BCD desktop app: (a) interactive city layers; (b) shadow analysis; (c) flood resilience; (d) visibility analysis

Shadow analysis is a 3D analysis of the shadow cast by a building or landscape object based on solar position. The effect of proposed large and tall buildings on the surrounding environment is a key aspect of planning appeals as it materially affects the quality of life for residents and workers. BCD Desktop/VR and MR include shadow simulation for a single day with soft and hard shadows simulations which are rendered together to increase photorealism (Figure 7b). The tool enabled an assessment of shadow impact and its length of time in an area.

Flood resilience is an acceptable level of flooding that the urban system can tolerate (Batica, et al., 2016). Flood risk management is important for urban areas as it may prevent or reduce the impacts of flooding and decrease the level of damage (Tucci, 2006). This feature is fully supported by the BCD project on all platforms including desktop using a toggle slider to raise and lower water levels (Figure 7c).

Visibility analysis provides an assessment of vistas and the impact of new developments on views and sightlines. They are used mainly for planning purposes, from new infrastructure implementation to the development of new buildings, routes, or other city landscape components. The tool creates an output raster that displays the terrain (Mat et. al., 2014) that can be seen from a specific point of view. Currently, this feature is available for the BCD Desktop version (Figure 7d) and is under development for VR and MR.

A key feature for planning 3D spatial media is the ability to add buildings to an existing landscape to assess their potential impact on the environment. We implemented three solutions to perform this task. The first was to enable 3D models of proposed buildings to be placed directly into the model, to move them about and to rotate and scale them to create unique building compositions and proposals. Currently, this feature was included in the BCD Desktop version of the project (Figure 8 a-d.). This feature is under development for VR/MR. A second option is to add a building from a predefined library, and to transform, rotate, scale, duplicate or remove it. Each object from the library contain their own texture, which is fixed. Using this tool, we can construct new buildings, green spaces or other landscape components (Figure 9a). We created a library of buildings for BCD MR to support city planning in mixed reality instead using simple planning feature (Figure 9d). A third tool enables the user to create and adapt a new building using a simple toolkit that specifies shape, size, number of floors, and roof shape and to alter these parameters in real-time for desktop (Figure 9b) and VR (Figure 9c).

Figure 8. BCD Desktop app: a run-time 3D building importer: (a) translation; (b) rotation; (c) scaling features; (d) multiple objects composition

Figure 9. Runtime 3D modeling tool, interactive buildings library: (a+b) desktop; (c) VR; (d) MR

FUTURE RESEARCH DIRECTIONS

Our research has highlighted that despite a couple of decades of research and development, 3D spatial media still lack maturity and there are many questions and technical challenges that require further fundamental and applied research. In particular, while games engines provide high quality graphics and user experience, they are poorly suited to handling spatial data and to act like a GIS. Fundamentally, the games engine has a different coordinate system with a fixed 0,0 origin and localized scale, and the main plane of movement is horizontal rather than vertical as with mapping systems. Importing and aligning spatial data is therefore not at all straightforward involving the rotation, centering and realignment of data, and constitutes a specialist task with no established procedure. Research is needed to make this process simpler and effective, to the point where a professional planner with moderate technical skills can achieve it quickly and effectively (at present this is not the case; indeed, it took us quite some time to solve this issue).

In addition, there is a need to investigate what the affordances and limitations of tools and tasks across platforms and to establish what works well for particular tasks, any shortcomings and potential solutions. This needs to involve user-testing by planners in planning environments on real planning tasks. It is clear to us that many commercial solutions have been driven by the technology and the ideas and aspirations of developers who may have little planning domain knowledge, rather than user requirements set out by practicing planners (Kitchin et al., 2021). Consequently, the use cases and tools of some systems do not align well with the work requirements and practices of the planning system. As a result, despite a fact that there is a noticeable growth in the development and commercial interest in 3D, BIM, CIM, and GIS software, there is still a lack of universal, multiplatform, and open-source solution with extensive functionality that matches planners' expectations, and this is likely to remain the case for some time without stakeholder-led research and development.

In our own case, the BCD project sought to provide an open-source CIM solution that works across desktop, VR and MR platforms. Using mixed reality technologies that combine GIS and CIM advances current research in the field. MR despite quite popular in entertainment industry it has not been well utilized for GIS and CIM related research, despite its obvious potential benefits. This technology in the future may be a help for planners who are considering the use of 3D spatial media for assessing planning options and making planning decisions. Our research is likely then to further investigate the development of a MR approach. This will include examining the desired functionality and how best to implement solutions, and HCI aspects concerning how users experience and utilize the system. Future project development may also include more features for multiuser MR solutions where more than a single user will be able to interact and explore the 3D planning environment using Microsoft HoloLens device.

CONCLUSION

Despite 30 years of research and development relating to 3D spatial media, and the creation of a number of functioning and affordable systems, such media have yet to become mainstream tools in professional planning. Indeed, while planners can see the potential benefits of using 3D spatial media, they remain somewhat skeptical of their adoption in the short-term due to data access and quality issues, technical capacity in planning departments, and the limited functionality and match-up to critical tasks in the planning process. Their perception is that even with further refinement and enhancements the technology will mostly prevail in the pre-planning process, rather than the processes of planning assessment, compliance and enforcement. Our project sought to evaluate the specifications and functionality of existing systems, and to use user requirement information and feedback from planners, to consider the design and production of a CIM that would address planner concerns and have utility for the everyday work of planning departments. Our aim was to design and develop an open source, multiplatform 3D spatial media solution that utilized games engine technology and included the functionality outlined in Table 1. The project combined GIS, CIM and XR, producing three platform applications (desktop/VR/MR) with five navigation modes: two for desktop (BCD desktop street view and bird's eye view, two for VR (street view and bird's eye view) and one for MR (bird's eye view). Developing three platforms enabled us to investigate the issues of building a CIM for different platforms, to explore their various affordances, and to examine the different types of experience and their possible consequences with respect to use. The resulting system provided a workable solution that planners felt was interesting and had potential utility, though they remained somewhat skeptical that such a system will be mainstreamed in the short-term due to institutional and cultural factors. Our research highlighted that involving planners in the design, build and testing will be important to help ensure that the systems developed are fit-for-purpose and to foster stakeholder buy-in.

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