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TOWARDS A VIRTUAL PLANNING SUPPORT THEATRE FOR CITY PLANNING AND DESIGN

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ABSTRACT:

In the era of ‘Smart Cities’, Planning Support Systems play an important role in providing a suite of digital tools to support evidenced based planning and design (Pettit et al. 2019). Planning Support Theatres vary from the traditional City Command Control Centres which are used to manage the real-time city (Kitchin 2014) in that they look at planning and design of future of cities and regions through collaboration (Healey 2003) between various stakeholders. Such methodologies which lend themselves to collaborative planning and design including Geo-design (Steinitz 2012; Pettit et al. 2019) and Co-design (Punt et al. 2020). There has been a plethora of virtual learning environments applicable to any discipline-specific application, each with their own names, terminology, feature sets and degrees of interoperability. In addition to providing the regular set of advantages such as ease of use across large geographies, improving collaboration between diverse set of stakeholders, these virtual platforms have become essential in the current world with travel restrictions and social distancing. In this context, it is imperative to explore the use of virtual systems for the purpose designing and implementing planning support theatre for city planning and design. This research builds a prototype for web based, 3D, immersive, planning support theatre and evaluates its functionality against similar physical theatres.

1. INTRODUCTION

Telecommuting is not a new concept, which came about with the 1970s emergence of technologies that enabled working remotely from home (Greer et al. 2002). However, it did not gain significant traction and our cities continued to function predominantly with workers coming into offices and students attending lectures in a face-to-face format. However, COVID-19, emission concerns and the isolation of people in their homes and the closure of international connections between many countries has provided significant challenges for how society and cities function (Alföldiová and Trnka 2020; Erikson 2021; Le et al. 2020). Florida (2010) discussed the great reset of our cities after a crisis. This is the situation we are facing today, and it is likely that cities won’t return to how they functioned previously with many in the workforce and business choosing to support a model where workers spend 2-3 days in the office and 2-3 days working remotely. This is of course not possible for all workers, but those in the creative class (Florida, 2019) and whose work is focused on the use of digital technology are looking for tools and environments which supported both remote and blended collaboration. It is in this context this research examines the development and evaluation of prototype virtual planning support theatres. We ask and try to answer th question: Can a virtual planning support theatre match the functionality and usability of their physical counterparts in supporting collaborative planning and design?

2. LITERATURE REVIEW

The literature on this topic presents many different terms noting a range of conceptually similar digital collaboration environments, each with particular specialisations specific for their purpose, including the generic Virtual/3D Collaborative Environments (Bochenek and Ragusa, 2003; Downey et al. 2012; Lorenzo et al. 2012; Afrooz et al. 2019; Stefan 2012), 3D-interactive virtual classroom (Chatwattana et al. 2020), Decision-Visualization Environments (Bragger et al. 2022, Baumgartner et al. 2022) encompassing Computer Supported Collaborative Learning (John et al. 2020) and social VR (Scavarelli 2021) domains such as Massively Multiuser On-line Learning Platforms (Montoya et al. 2011). Mozilla Hubs has been described as a social virtual environment platform (Le et al. 2020), and Second Life a three-dimensional (3D) electronic environment (Wang and Braman 2009). Despite the lack of a consistent terminology, there is a generally shared understanding of what these environments are and what they should do. In this paper we focus on the UNSW City Analytics Lab and the creation of a Planning Support Theatre (PST) (Punt et al. 2020). A growing number of PSTs support applied, and collaborative planning and design are becoming a reality.

Relatively early work such as Montoya et al. (2011) acknowledge the challenges of virtual interaction compared to actual physical interaction. Montoya et al. (2011) examined the link between collaborative behaviour and virtual team performance. Studying 39 virtual teams of 91 individuals, distinct patterns of collaborative behaviours were identified. Using objective measures, results showed participants in the immersive Second Life environment performed with better communication and coordination while communicating with less frequency, suggesting a greater quality of communication. Users noted learning curves and familiarity as barriers. Metrics for group participation were extracted from logs to measure equity in participation or identify ‘free-riders’.

Lorenzo et al. (2012) recognised environments offering synchronous communication in an explicit social setting required further research to objectively gauge their effectiveness. 21 technology-mediated teaching and learning graduate students participated in the “MadriPolis” project, using Social Network Analysis to gauge the effectiveness of virtual learning worlds compared to conventional Learning Content Management System (LCMS) to contrast outcomes and interaction patterns. The study showed that density and centrality measures were observed to improve when using the

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virtual learning worlds, and they enhanced both tutor interaction and group relationship strength.

Ştefan (2012) studied 3D immersive and collaborative educational environments as a support for "constructivist and experiential learning models, appropriate for artistic education and skill transfer, for teaching and learning the art of traditional design" comparatively analysing educational environments in Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR). It was noted these environments improved students' "3D spatial skills, cultural awareness, self-training and social and professional collaboration". Ştefan et al. (2016) went on to note that despite the existence of a plethora of examples of virtual learning environments having emerged, these initiatives were still largely bound to academic research contexts and an implementation gap existed with limited uptake by professionals. Ştefan et al. (2016) conducted a synthetic evaluation of an experimental learning environment of graphics classes and compared findings against a similar evaluation performed using the Moodle Learning Management System. Results showed the virtual environments provided better engagement and motivation, but required greater effort for an effective instructional design, recommending improved Moodle integration and mixed reality experiences.

2.1 Existing Planning Support Theatres

2.1.1 City Analytics Lab (CAL), UNSW, Australia

Punt et al. (2020) analysed 15 workshops and surveyed 89 planning practitioners to assess CAL's use in supporting smart planning and bridging the PSS implementation gap. Users were positive towards the usefulness and usability of support tools, the collaborative/ interactive tables and software and generation of interactions new ideas. Further development opportunities were identified to address the PSS implementation gap and reduce technology adoption barriers by continued co-design of tools and protocols between users, developers, planning practice, local governments, industry partners and other universities.

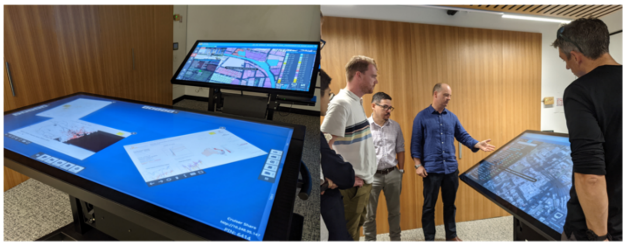

Figure 1: Collaborative interactive tables in planning theatre of City Analytics Lab, UNSW, Sydney

2.1.2 CityScope, MIT, USA

As engagement processes concerning urban transformation are strongly reliant on visual communication, negotiation and coordination between multiple stakeholders, MIT's CityScope platform, created by the MIT City Science Group, helps build consensus and optimise design outcomes by providing a real-time, tangible interface for simulating interventions on urban ecosystems prior to proceeding with a full design process (Alonso et al. 2018) It has been used to develop an internationally applicable urban wellbeing index encompassing Community Connectedness, Safety & Security, Physical Health, Mental Health, and Diversity in a series of American cities (Orii et al. 2020), and also a framework to understand visitor flow and behaviour in Andorra using multi-level interactive and tangible agent-based visualization (Grignard et al. 2018). During these projects, extensive testing in workshops, classes, and demonstrations support the platform as an efficient civic engagement tool.

2.1.3 iHub Swinburne, Australia

The hub project focusses on the interconnectedness of energy, water, transport, waste, and housing domains to assist in regenerative urban development, decarbonisation and climate adaptation initiatives working from strategic National/metropolitan scales to tactical neighbourhood-scale projects. A key operation of the system is in enabling structured interaction between multiple urban stakeholders by "real-time synchronous collaboration, visioning, research synthesis, experimentation and decision-making techniques" (Newton and Frantzeskaki, 2021). This engagement layer includes a reconfigurable laboratory space fitting 30 people with four pods acting as break-out spaces to facilitate real-time visualisation of urban analytic scenarios, interactive presentations and facilitated peer-peer communication. Newton and Frantzeskaki (2021) state that "[t]he engagement layer is where the major benefits of the hub network are delivered: imagine politicians, planners, developers, architects, engineers, social scientists, and citizens being able to gather in a room to make collective decisions based on real-time data analytics".

2.1.4 Decision Support Theatre: Arizona State University, USA

This PST has been used to support research, planning and decision making in architecture, forest science, urban design and other domains at the science-society-policy interface to explore climate change impacts, resource management practices and urban design solutions (Boukherroub et al. 2018). John et al. (2020) undertook a detailed analysis of the entire institution, creating an analytical framework describing the system components and designing the overall participatory collaborative workflow and process. A comparative analysis of seven international PST facilities was based on expert interviews, site visits, and document review. Results revealed commonalities across 53 attributes including planning, stakeholder involvement and realization of PST activities, revealing the opportunity for an active PST network to build an inter-institutional learning community to pool/coordinate activities and share experiences John et al. (2020). The study revealed many insights, including the importance of the experience providing a "sense of being there", the capacity for self-directed knowledge creation (Barth and Burandt 2013) and experimentation or manipulation or exploration beyond explanatory approaches that recognise "the interplay of uncertainty, choice, and constraints" (Salter et al. 2010). It was noted that these systems worked best to build user capacity by "providing background information, negotiating options and exercising collaborative planning, allowing for an informed decision-making process at a later stage". Similarly, the role of facilitation was reenforced to best direct the user experience by maintaining a specific narrative/storyline to iterate and repeat important points and provide scaffolding for subsequent tasks. It was noted the complexity and novelty of PST's, including the physical context, could overwhelm participants (Sheppard and Meitner 2005), and indeed the geographic location of the PST complicates accessibility and emotional distance to the real-world problem at hand - suggesting mobile kiosks/exhibition facilities or mobile devices operated on-site provide a clear advantage. The authors note that "creating an enabling environment and inclusive conversation is challenging and requires future development", proposing further evaluation strategies measuring success and effectiveness of processes to better understand the impact on implementation and policy (Pahl-Wostl 2009; Radinsky et al. 2017; Sheppard et al. 2011).

2.2 Popular Virtual Platforms

2.2.1 Mozilla Hubs

Erikson (2021) documented the duration of a fully online Digital Movie Making course. As students were showing signs of "Zoom fatigue" during the COVID-19 pandemic, lectures, seminars, and supervision were performed using the Mozilla Hubs social VR platform. The platform was chosen for its ability for students to create and customise their own spaces, openness, and accessibility via conventional web browser. The platform operated as intended when used only for the supervision of small student groups only. It was noted the platform had a series of usability and technical flaws, being clumsy to use and suffering audio/technical issues when all 25 students attended a lecture simultaneously- however these issues were also present in trials with the Second Life environment. It was noted the set-up time for Mozilla was comparable to setting up a similar Zoom meeting; VR environments had the benefit of conveying gestures and body language (Erikson 2021). Le et al. (2020) used Mozilla Hubs for a live streaming conference, focussing on social interactions, user experience, design aspects and motivation. Respondents reported a reasonable experience for watching talks remotely, noted improved social connectivity and rated overall experience as very satisfying. Participants valued having options of using different devices and the ability to explore spaces – although 'flying' users would block to view of the lecture for other participants. It was noted the rooms would have benefitted from more participants by providing a richer interactive experience. The technology was noted as improving and performing better during this study compared to previous work.

2.2.2 Second Life

Downey (2012) performed a small-scale study (n=42) exploring learner's perceptions and recall when using Elluminate (Blackboard Collaborate) and Second Life. Results show learners observing discussions in Second Life have "a tendency to better organise ideas, better identify who said what, and better recall what information was said throughout the discussion", 10-13% better than in Elluminate alone. Wang and Braman (2009) ran a series of field trials for up to 60 students and presented a case study of an introductory computer course using Second Life. They found that the integration of Second Life improved students' learning experience and evidence of higher learning motivation and better performance. It was noted that the high system requirements of Second Life resulted in the platform running sub-optimally on available machines. Also, user familiarity with virtual environments was a factor in user experience, requiring tailored training sessions to help on-board all users.

Other platforms are emerging, including Sansar, launched in 2017 as a successor to Second Life, are building their own engine for the platform to compete with Unreal and Unity. This platform has most recently been deployed to host a virtual music festival, Splendour XR. This festival traditionally drew 50K ticket buyers, however the twitter account has only 40K followers, and each 'stage' or 'instance' of the festival can host 60 interacting avatars online. User feedback was generally positive, with main issues surrounding access without specialised equipment not permitting interactive experience and presenting other technical issues (Guardian 2021). In terms of other platforms of interest, CryptoVoxels is another emerging platform, combining a Minecraft-style voxel-based world using Blockchain technology to provide a ledger of custodianship and participant activity. CESIUM/ TerriaJS (Belgun et al. 2015) is an open platform that may interoperate with established GIS formats or other software, such as Unreal engine, to host 3D/4D environments. In the Australian context, it has become a default platform for intergovernmental data sharing, with a growing number of government organisations interfacing with the platform. Notably, the emergence of the Digital Twin concept has reenforced the demand for easily sharable, standardised data publishing and ingestion between federated networks.

2.2.3 Immersive Terf

Immersive Terf is a proprietary platform that has been used to facilitate Geo-design in the context of architecture, urban planning, and design in undergraduate and graduate Built Environment courses (Afrooz et al. 2019). The game-like environment provides functionality for live voice/video, webcam operation, chat, and embedded virtual presentation tools. Students can demonstrate projects in real/ non-linear time, simultaneously navigating and communicating to their tutors. This provides the opportunity for immediate feedback, new forms of design assessment and deep learning outcomes. Feedback on usage and functionality was collected from students through post evaluation surveys. Results showed that TERF performed well in engaging students as a pedagogical tool by promoting collaborative learning and teaching. Issues encountered included time required for preparation and production of assignments, and although the system permitted importing building/precinct data, the size of these model's substantially slowed performance.

2.2.4 Unity

Unity has been used regularly to create gamified learning environments with quality 3D modelling, lighting, rendering and textures, combined with platforms like JanusVR browser (https://www.janusvr.com/), repositories like SketchFab (https://sketchfab.com/) and devices such as Oculus Rift. Studies using these technologies report improvements in quality of learning, engagement, motivation, interest, attention, and creativity in comparison with conventional methods and resources (Vicent et al. 2015, Wang 2018). Chatwattana et al. (2020) had successful results using Unity on handheld devices running Android version and delivering satisfying lighting/shading, resolution, motion, and aliasing - this was shown to improve students' imagination and efficient learning of new skills and knowledge (Syamsuddin and Kwon 2010; Chatwattana et al. 2020). Vurpillot et al. (2018) suggest online environments offer an open and accessible environment by removing the hurdle of specialised/proprietary software installation, format and platform constraints while providing a platform for flexible development and debugging. Gonzalez et al. (2017) have used Unity as a tool supporting physics teaching when facing limited availability of laboratories, citing the platform's video hardware management and control over delivery to mobile devices, web browsers, consoles, and desktops as a comparative advantage. Dong et al. (2021) used Unity as a platform in conjunction with Rhino, 3ds Max and C# to create a teaching/training environment for Chinese jade carving, with the aim of increasing teaching and learning efficiencies while overcoming limited space, time, and material. Fifteen students were surveyed, and the reliability and effectiveness of the system was confirmed. Juliani et al. (2018) promote the use of modern game engines as flexible, interactive, and easily configurable general platforms to provide learning environments rich in visual, physical, task,

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and social complexity. In this project, the Unity platform was used along with the Unity ML-Agents Toolkit to tune functionalities within the environment. It is important to note that the above cover some of the popular virtual platforms, there are multiple upcoming and established alternatives which are not discussed here such as virbela, metaverse, rumii, spatial etc.

3. DESIGN AND DEVELOPMENT

3.1 Conceptual Design

Establishing a platform that would support different planning tasks requires identifying the right technologies that should be integrated. As mentioned previously, Unity provides the option to integrate plugins natively and from other sources. Another advantage of Unity compared to many platforms is the option to build almost simultaneously an application for different platforms such as Android, iOS, WebGL, PC, Mac and many others. In our case, we are interested in creating a web platform that will enable students and other users to easily access the application. Another two components that play significant roles are Photon (i.e., a networking engine for multiplayer applications), and MySQL (i.e., a database solution for storing static information). Thus, the targeting platform will be the core of the system interacting with Photon and MySQL (Figure 2). Unity allows off-the-shelf integration of many components in an application. In our case, Unity is used to build the user interface and interactions of a user with the application and other users. In the editor that Unity provides the 3D environment, interactive panels and the main screen are imported. To enable playing videos and giving presentations, the VideoPlayer component is utilised.

To support different interactions between users in real-time Photon server is selected. The plugin supports different ways of communication depending on the frequency of updates required for a specific task. Thus, for position update of avatars, we can use the continuous update, while for other updates (e.g., slides presentation update) that are not coming often less bandwidth-demanding network options are selected. Photon also provides natively chat and voice support. However, the voice communication plugin does not support WebGL. Therefore, the Voice Pro plugin is selected to deal with this issue. This plugin is using Photon in the background to distribute voice communications between users.

MySQL provides an option to store and retrieve static information. There are many possibilities to use MySQL along with the targeting platform for different tasks. In our case, the database is used to store messages related to interactive panels and planning proposals presented on them.

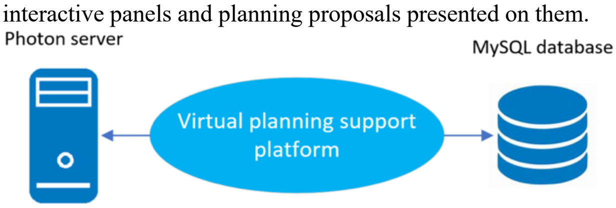

Figure 2: Conceptual design

The goal of this project is to create a replica of the UNSW City Analytics Lab having the same capabilities and allowing interactions between users. A 3D model representing the lab is imported as an obj file as well as models of 6 interactive panels. Figure 3 shows the main room of the lab where the interactive panels are located. Each interactive panel allows visualising an image of different planning proposals and some interactions with it. A user needs to enter an area to start interacting with a panel. The areas are also presented in Figure 3 with the size of 3 x 2 x 2 meters. Users that are in the same area can talk to each other as well. The main screen located in the centre of the room can be used for video presentations and planning proposals.

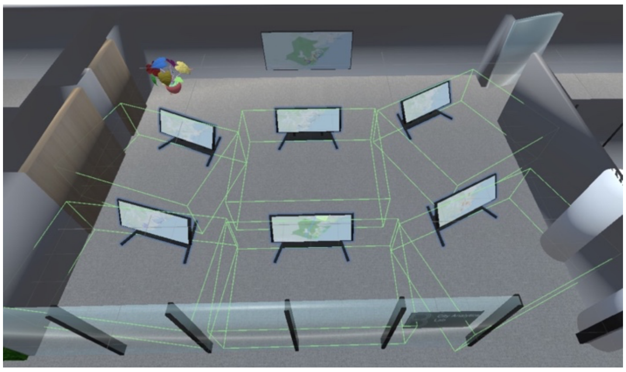

Figure 3: Virtual room for urban planning support

3.2 Session design

At the start to join a session users need to insert their name and pick an avatar for navigation through the environment. They have the option to select between 10 male and 10 female avatars that can be rotated on click to see them in 360 degrees (Figure 4).

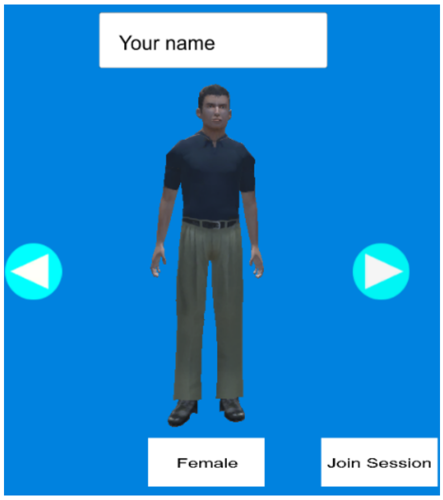

Figure 4: Selection of an avatar before joining a session

Once they join the environment, using a third person controller they can freely move using their keyboard arrows and mouse. With the scroll wheel, they can zoom in and out to some extent if needed. Other users have above their avatars a label of their names, which will rotate towards the main player to know who is in their proximity.

On the left, a menu can be opened having several options related to voice control, presentation, position restart, and chat (Figure 5). Thus, the user can select one of the available microphone options, turn on and off their microphone as well as mute all users. Regarding the presentation, once a user selects to give a presentation the Photon server will inform other users about it and turn off the presenter button for selection. The user should insert the name of a pre-uploaded presentation and click on Zoom to presentation to be transferred in front of the main screen. If users want to return to the initial position or get stuck somewhere, they can click on the restart button for it. The chat allows users to write down comments and communicate effectively with each other.

Figure 5: User presence and capabilities of the platform

When it comes to the interactive panels, the main idea is to replicate their capabilities. The first and the main aspect that should be dealt with is the image that we want to render on an interactive panel. The interactive panels in the UNSW City Analytics Lab have the option to show a map coming from a website. In our case, since we want to achieve the same in the WebGL we would need to render a webpage within a webpage. At the moment there is not a suitable solution that will achieve this. Therefore, the solution that we propose is to take a print screen from a website which we use to explore different planning designs every N second and render the image on an interactive panel. To see the latest image the user should use right-click. In this way, the latest view of the map will be presented which users can explore and discussed. Users have the option to use their mouses and point at any location on the map which will synchronise the mouse position across the network and present it to other users as shown in Figure 6.

Figure 6: A user exploring an urban plan. In the bottom right, a pointer showing the mouse position is presented in yellow.

Regarding the presentation mode, no plugin for Unity allows using PowerPoint presentations. Therefore, the strategy that we take is to consider presentations in mp4 format, which we can pause, move forward and backwards. Unity allows visualising video files through the Video Player component (Figure 7). The workflow requires exporting a presentation as an mp4 file from PowerPoint where the time interval between slides is set to 5 seconds. Once the presentation file is uploaded to the server by using the keyboard arrows a presenter can move left and right in the presentation considering the interval. The slide position will be sent across the network to other users, and they would be able to follow the presentation.

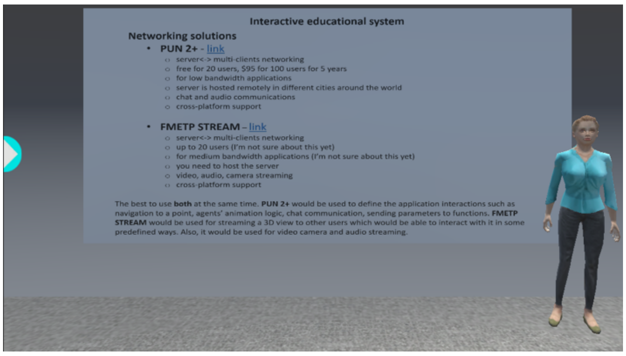

Figure 7: A person giving a presentation

4. EVALUATION AND DISCUSSION

4.1 Features & Functionality

As highlighted in the literature, there is a rising need for making planning support theatre platforms accessible to remote participants attending with various type of devices. Online meeting/video-conferencing systems such as MS Teams, Zoom and 3D Virtual meeting platforms such as Mozilla Hubs provide some of these features, but they reduce overall functionality in other places. In this context, it is important to evaluate the features of the proposed virtual planning support theatre in contrast to the existing City Analytics Lab in UNSW and other solutions to evaluate its strengths and weaknesses. Table 1 compares the features and functionality required by an ideal planning support theatre with what is being covered in a prototype of the Virtual City Analytics Lab built in this work. It also compares its features to generic video-conferencing platforms and hybrid approaches in integrating them in planning support theatres.

We can observe that the primary shortcomings of the physical planning theatres are remote access, scalability in terms of having multiple parallels spaces for multiple uses, and easy customisation of the environment. The virtual meeting / video conferencing platforms solve the shortcomings of remote access and scalability, but they affect the immersion aspect of the environment thus taking away more the subtle advantages of a physical environment such as significance of physical adjacency and ability to have multiple concurrent conversations in the same room. Being general-purpose tools, they are usually not suitable for specific needs of planning support use case.

Although the hybrid approach where remote participants attend the planning support theatres using video-conferencing platforms attempts to achieve the best features of both physical and online platforms, they still have the shortcomings in terms of scalability. The hybrid systems usually cannot be scaled beyond the capacity of what is offered by the physical theatre.
The prototype virtual planning theatre platform provides most of the functionalities required by a planning support studio and makes it easily scalable to multiple users who are accessing remotely. The room/environment can be easily customised as required and replicated based on the number of applications thus theoretically can be scaled to very large number of users. Although some functionalities are still lacking, such as ability to display dynamic web content and recording, they could be achieved in future iterations of platform provided the resources.

	Feature / functionality	Planning Support Theatre	Planning Support Theatre (Hybrid)	Conferencing (Zoom etc.)	Virtual Planning Support Theatre
Immersion and Environment	Planning theatre room	x	x		x
	Media wall	x	x		x
	Touch screen tables	x	x		x
	Customising room layouts	x	x		x
	Adding extra equipment	x	x		x
Participants	3D avatars		x		x
	Customising the avatars		x	x	x
	Freely move in the room	x	x		x
	Switch/move between tables.	x	x		x
Interaction	Text			x	x
	Audio	x	x	x	x
	Face to face (Video)			x	
	Face to face (3d avatar)	x	x		x
	Presentation to audience	x	x	x	x
	Handover control to each other	x	x	x	x
	Spatial adjacency	x	x		x
	Group in teams & groups	x	x	x	x
	Broadcast from own devices		x	x	
Tables & Media wall	Display static content	x	x	x	x
	Display dynamic content	x	x	x	
	Collaborative whiteboard	x	x	x	
	Add comments and notes	x	x		x
	Store comments and notes	x	x		x
	Send comments and notes between tables	x	x		
	Store the state of the table	x	x		
Other Features	Customisation of the room				x
	Interoperability			x	x
	Recording	x	x	x	
	Ease of scaling			x	x
	Remote access		x	x	x

Table 1: A comparison of features of various forms of PSTs with the virtual PST.

4.2 Usability

Evaluating the usability of the web-based platforms for planning support and the incorporation of the findings into the development in an iterative manner is important for delivering the best experience for the users of such platforms (Russo et al. 2018a, 2018b). Such user centric design and development process can be carried out using various methods including but not limited to - surveys, focus groups, task-based scenarios and thinking aloud workshops etc. among a representative sample of users (Barton 2015). Eye tracking based studies could also be used for such usability studies but considering the 3D nature of the platform they were not suitable for the proposed platform.

Considering the above, a task-based scenario was developed and a think aloud session along with a post session questionnaire was undertaken with broader project team outside the technical development to understand the usability of the platform along with its problems. The session was conducted virtually over MS Teams where the participants acting as two groups of policy makers, were given two different options in terms of locating a new train station in eastern Sydney. The groups viewed, discussed, and evaluated the scenarios collaboratively and decided on which scenario to choose. The task used the RAISE toolkit to create the scenarios which were exported to the virtual lab for the collaborative discussion. The moderator recorded the session and the discussion between the participants and facilitated a post study questionnaire collecting the feedback from the users. Two such sessions were conducted, and the feedback received from the sessions range from technical issues such as visibility of interface elements to broader requirements such as 'transparency' of the interface where the functionality of the interface is readily visible to the users without further training. These feedback from the surveys were recorded and used to improve the functionality of the platform in the subsequent iterations. While the primary positive feedback received was that the participants felt more engaged in the process because of the interactivity offered by the virtual lab, most of the feedback were around the issues faced in achieving a smooth seamless session which are detailed below.

4.3 Challenges

Although most of the functionality of the physical lab could be replicated in creating the virtual version, the endeavour posed many unique challenges in the process as highlighted by the testing and evaluation process. The first and foremost challenge faced is the synchronisation and management of multiple avatars in a real time manner. Unity and photon provide us with a simplified way of doing this using their platform but the application when scaled beyond a certain number of users such as 50 leads to race conditions and associated visual artefacts. This makes the current version of the platform not usable for large groups of participants and further work is needed on improving the scaling aspect of the platform. In addition to the virtual avatars, the scaling problem extends to the voice communications between them as well. Without advanced features such as noise cancellation, switching audio stream focus based on voice recognition, multiple geographically distributed low latency servers etc. the voice communications in the platform cannot be conducted between more than few people at a time. Currently this issue has been solved by constraining voice communication between physically close participants in the virtual lab. Finally, the major challenge in applying the virtual lab for geo-design applications is the inclusion of Geo-spatial viewing and editing functionality to the participants in real-time 3D using Unity. Although visualising the geospatial data as 3D objects could be achieved easily, making these 3D objects editable and reflecting the changes to all the participants in real-time for live discussion proved to be a non-trivial problem which require development of dedicated set of tools and libraries for the unity platform.

5. CONCLUSIONS

As seen in the literature, there has been extensive work done in designing, building, and deploying tools, frameworks and platforms for online, collaborative working since the last 20 years. The adoption of such platforms for various forms of collaborative, remote work environments has been the need of the hour since the start of COVID19 pandemic. We have seen the rise of use of A/V conferencing platforms such as Zoom, Teams etc extensively to enable people to carry out their work safely and remotely. This work has looked at designing, building, and evaluating such a platform for creating an online, virtual, immersive, 3D environment which can act as virtual planning support theatre for participants to conduct collaborative planning and geo-design process. In this work we looked at the existing physical planning support theatres such as CityScope - MIT, City Analytics Lab – UNSW and Decision Support Theatre – ASU and surveyed toolkits and platforms such as Mozilla Hubs, Second Life, Unity etc. for their suitability in building a virtual version of these Physical facilities. Ultimately, we chose the Unity platform along with the Photon extension to design a virtual planning support theatre which simulates the real City Analytics Lab. The Virtual Lab was built and deployed as a immersive, interactive, 3D web application which lets the users to use the facility in real time with each other. The Virtual city analytics lab consists of the main planning theatre and lets the users to select an avatar and physically walk around the space. It also enables the user to use voice to communicate between them when they are close to each other. The touch tables from the real facility have been simulated in the virtual lab as dynamic surfaces which can show images from a web location and multiple people can point at the surface using a virtual pointer. The virtual video wall has been equipped with a presentation feature where the participants can display a video file in real-time to other users. The application also has hybrid overlay with 2D user interface such as text-based chat function. When comparing the features of this virtual planning theatres with other options we find that this platform combines the safety, convenience, and scalability of an online platform with the immersion offered by the physical space. Although not implemented now, the virtual lab can theoretically offer features of the conferencing platforms such as audio/video recording, attendance and engagement monitoring etc. We also conducted task-based sessions with limited participants using the platform to understand its usability. The feedback such as proximity-based audio filtering was implemented while issues and challenges were documented. The major challenge for the platform is the latency of synchronising the participants in real-time. Although the platform as a prototype can support around 5 users, there needs to be work done in scaling this to more participants. This is imperative for data intensive streams such as voice and video if they need to be useful for the participants. The prototype implementation provides a starting point for further work such as reducing the latency and responsiveness, improving 3D geospatial capabilities. This work aims to be the first of many steps needed in developing the conceptual framework for building a virtual planning support theatre which would be an important addition to the expanding toolkit for collaborative work in planning and policy making.

REFERENCES

Afrooz, A., Ding, L., & Pettit, C. (2019, July). An immersive 3D virtual environment to support collaborative learning and teaching. *In International Conference on Computers in Urban Planning and Urban Management* (pp. 267-282). Springer, Cham.

Alföldiová, A. & Trnka A. (2020). How The Covid-19 Pandemic Has Affected The Virtual Economy In Second Life. *Marketing Identity*: Covid-2.0, 14-21.

Alonso, L., Zhang, Y. R., Grignard, A., Noyman, A., Sakai, Y., ElKatsha, M., Doorley, R. & Larson, K. (2018, July). Cityscope: a data-driven interactive simulation tool for urban design. Use case volpe. *In International conference on complex systems* (pp. 253-261). Springer, Cham.

Barth, M., & Burandt, S. (2013). Adding the "e-" to learning for sustainable development: Challenges and innovation. *Sustainability*, 5(6), 2609-2622.

Barton, J. E., Goldie, X. H., & Pettit, C. J. (2015). Introducing a usability framework to support urban information discovery and analytics. *Journal of Spatial Science*, 60(2), 311-327.

Belgun, A., Grochow, K., Henrikson, M., Leihn, P., Mason, A., Raghnaill, M. N., Ring, K., Simpson-Young, B., Coetzee, Serena M., Cooper, A.K., Camboim, S. & Anand, S. (2015). *The Australian National Map. Proceedings of a pre-conference workshop of the 27th International Cartographic Conference*. (pp. 5-8).

Bochenek, G. M., & Ragusa, J. M. (2003, January). Virtual (3D) Collaborative Environments: An improved environment for integrated product team interaction? *In 36th Annual Hawaii International Conference on System Sciences*, 2003. (pp. 10-pp). IEEE.

Boukherroub, T., D'amours, S., & Rönnqvist, M. (2018). Sustainable forest management using decision theaters: Rethinking participatory planning. *Journal of Cleaner Production*, 179, 567-580.

Bragger, L., Baumgartner, L., Koebel, K., Scheidegger, J., Çöltekin, A. (2022, in press). Interaction and visualization design considerations for gaze-guided communication in collaborative extended reality. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*.

Baumgartner, L., Bragger, L., Koebel, K., Scheidegger, J., Çöltekin, A. (2022, in press). Visually annotated responsive digital twins for remote collaboration in mixed reality environments. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*.

Chatwattana, P., Kuntama, K., & Phadungthin, R. (2020). A 3D-interactive virtual classroom with a virtual learning environment. *World Transactions on Engineering and Technology Education*, 18(4), 387-392.

Dong, B., Pan, S., & Fu, R. (2021, July). Design and Research on the Virtual Simulation Teaching Platform of Shanghai Jade Carving Techniques Based on Unity 3D Technology. *In International Conference on Human-Computer Interaction* (pp. 571-581). Springer, Cham.

Downey, S., Mohler, J., Morris, J., & Sanchez, R. (2012). Learner perceptions and recall of small group discussions within 2D and 3D collaborative environments. *Australasian Journal of Educational Technology*, 28(8).

Eriksson, T. (2021, May). Failure and success in using mozilla hubs for online teaching in a movie production course. *In 2021 7th International Conference of the Immersive Learning Research Network (iLRN)* (pp. 1-8). IEEE.

Florida, R. (2010). The great reset: How new ways of living and working drive post-crash prosperity. *Random House Canada*.

Florida, R. (2019). The Rise of the Creative Class. Hachette UK.

González, J. D., Escobar, J. H., Sánchez, H., De La Hoz, J., & Beltrán, J. R. (2017, December). 2D and 3D virtual interactive laboratories of physics on Unity platform. *In Journal of physics: conference series* (Vol. 935, No. 1, p. 012069). IOP Publishing.

Greer, J. A., Buttross, T. E., & Schmelzle, G. (2002). Using telecommuting to improve the bottom line: the benefits definitely seem to outweigh the costs. (Cash Management). *Strategic Finance*, 83(10), 46-50.

Grignard, A., Macià, N., Alonso Pastor, L., Noyman, A., Zhang, Y., & Larson, K. (2018, July). Cityscope andorra: a multi-level interactive and tangible agent-based visualization. *In Proceedings of the 17th International Conference on Autonomous Agents and MultiAgent Systems* (pp. 1939-1940).

Guardian (2021) https://www.theguardian.com/culture/2021/jul/26/splendour-xr-virtual-music-festival-was-an-eerie-empty-reminder-of-what-weve-lost

Healey, P. (2003). Collaborative planning in perspective. *Planning theory*, 2(2), 101-123.

John, B., Lang, D. J., von Wehrden, H., John, R., & Wiek, A. (2020). Advancing decision-visualization environments—Empirically informed design recommendations. *Futures*, 123, 102614.

Juliani, A., Berges, V. P., Teng, E., Cohen, A., Harper, J., Elion, C., Goy C., Gao Y., Henry H., Mattar M., & Lange, D. (2018). Unity: A general platform for intelligent agents. *arXiv preprint* arXiv:1809.02627.

Kitchin, R. (2014). The real-time city? Big data and smart urbanism. *GeoJournal*, 79(1), 1-14.

Le, D. A., Maclntyre, B., & Outlaw, J. (2020, March). Enhancing the experience of virtual conferences in social virtual environments. *In 2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)* (pp. 485-494). IEEE.

Lorenzo, C. M., Sicilia, M. Á., & Sánchez, S. (2012). Studying the effectiveness of multi-user immersive environments for collaborative evaluation tasks. *Computers & Education*, 59(4), 1361-1376.

Montoya, M. M., Massey, A. P., & Lockwood, N. S. (2011). 3D collaborative virtual environments: Exploring the link between collaborative behaviors and team performance. *Decision Sciences*, 42(2), 451-476.

Newton, P., & Frantzeskaki, N. (2021). Creating a national urban research and development platform for advancing urban experimentation. *Sustainability*, 13(2), 530.

Orii, L., Alonso, L., & Larson, K. (2020). Methodology for Establishing Well-Being Urban Indicators at the District Level to be Used on the CityScope Platform. *Sustainability*, 12(22), 9458.

Pahl-Wostl, C. (2009). A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global environmental change*, 19(3), 354-365.

Pettit, C., Hawken, S., Ticzon, C., & Nakanishi, H. (2019, July). Geodesign—A tale of three cities. *In International Conference on Computers in Urban Planning and Urban Management* (pp. 139-161). Springer, Cham.

Punt, E. P., Geertman, S. C., Afrooz, A. E., Witte, P. A., & Pettit, C. J. (2020). Life is a scene and we are the actors: Assessing the usefulness of planning support theatres for smart city planning. *Computers, Environment and Urban Systems*, 82, 101485.

Radinsky, J., Milz, D., Zellner, M., Pudlock, K., Witek, C., Hoch, C., & Lyons, L. (2017). How planners and stakeholders learn with visualization tools: using learning sciences methods to examine planning processes. *Journal of Environmental Planning and Management*, 60(7), 1296-1323.

Russo, P., Lanzilotti, R., Costabile, M. F., & Pettit, C. J. (2018a). Adoption and use of software in land use planning practice: A multiple-country study. *International Journal of Human–Computer Interaction*, 34(1), 57-72.

Russo, P., Lanzilotti, R., Costabile, M. F., & Pettit, C. J. (2018b). Towards satisfying practitioners in using Planning Support Systems. *Computers, Environment and Urban Systems*, 67, 9-20.

Salter, J., Robinson, J., & Wiek, A. (2010). Participatory methods of integrated assessment—a review. Wiley Interdisciplinary Reviews: *Climate Change*, 1(5), 697-717.

Scavarelli, A., Arya, A., & Teather, R. J. (2021). Virtual reality and augmented reality in social learning spaces: a literature review. *Virtual Reality*, 25(1), 257-277.

Sheppard, S. R., & Meitner, M. (2005). Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups. *Forest ecology and management*, 207(1-2), 171-187.

Sheppard, S. R., Shaw, A., Flanders, D., Burch, S., Wiek, A., Carmichael, J., Robinson J. & Cohen, S. (2011). Future visioning of local climate change: a framework for community engagement and planning with scenarios and visualisation. *Futures*, 43(4), 400-412.

Ștefan, L. (2012). Immersive collaborative environments for teaching and learning traditional design. *Procedia-Social and Behavioral Sciences*, 51, 1056-1060.

Stefan, L., Moldoveanu, F., & Gheorghiu, D. (2016). Evaluating a mixed-reality 3D virtual campus with big data and learning analytics: A transversal study. *Journal of e-Learning and Knowledge Society*, 12(2).

Steinitz, C. (2012). A framework for geodesign: Changing geography by design. ESRI Press.

Syamsuddin, M. R., & Kwon, Y M. (2010, July). Research on virtual world and real-world integration for batting practice. *In 2010 International Symposium on Ubiquitous Virtual Reality* (pp. 44-47). IEEE.

Vicent Safont, L., Villagrasa, S., Fonseca Escudero, D., & Redondo Domínguez, E. (2015). Virtual learning scenarios for qualitative assessment in higher education 3D arts. *Journal of universal computer science*, 21(8), 1086-1105.

Vurpillot, D., Verriez, Q., & Thivet, M. (2018). Aspectus: A Flexible Collaboration Tool for Multimodal and Multiscalar 3D Data Exploitation. *Studies in Digital Heritage*, 2(2), 150-165.

Wang, D. (2018). Exploring a narrative-based framework for historical exhibits combining JanusVR with photometric stereo. *Neural Computing and Applications*, 29(5), 1425-1432.

Wang, Y., & Braman, J. (2009). Extending the classroom through Second Life. *Journal of Information Systems Education*, 20(2), 235.