SCHNABEL, M.A., KOBAYASHI, Y., PENCREACH, Y., BENNADJI, A., CHOI, D., FIAMMA, P., FUKUDA, T., LO, T.T., NARAHARA, T., NOVAK, M., RON, R., SWARTS, M., TERZIDIS, K., TUCKER, T. and VITAL, R. 2021. Virtual World16: virtual design collaboration for the intersection of academia and industry. In Globa, A., van Ameijde, J., Fingrut, A., Kim, N. and Sky Lo, T.T. (eds.) *Proceedings of the 26th Association for Computer-Aided Architectural Design Research in Asia international conference 2021 (CAADRIA 2021): projections*, 29 March - 1 April 2021, [virtual conference]. Hong Kong: CAADRIA [online], vol 2, pages 203-212. Available from: https://caadria2021.org/wp-content/uploads/2021/03/caadria2021_318.pdf

Virtual World16: virtual design collaboration for the intersection of academia and industry.

SCHNABEL, M.A., KOBAYASHI, Y., PENCREACH, Y., BENNADJI, A., CHOI, D., FIAMMA, P., FUKUDA, T., LO, T.T., NARAHARA, T., NOVAK, M., RON, R., SWARTS, M., TERZIDIS, K., TUCKER, T. and VITAL, R.

2021

VIRTUAL WORLD16

Virtual Design Collaboration for the Intersection of Academia and Industry

MARC AUREL SCHNABEL[1], YOSHIHIRO KOBAYASHI[2],
YOANN PENCREACH[3], AMAR BENNADJI[4], DONGSOO CHOI[5],
PAOLO FIAMMA[6], TOMOHIRO FUKUDA[7], TIAN TIAN LO[8],
TARO NARAHARA[9], MARCOS NOVAK[10], RUTH RON[11],
MATTHEW SWARTS[12], KOSTAS TERZIDIS[13],
THOMAS TUCKER[14] and REBEKA VITAL[15]
[1]*Victoria University of Wellington*
[1]*MarcAurel.Schnabel@vuw.ac.nz*
[2]*Arizona State University*
[2]*dr.yoshihiro.kobayashi@gmail.com*
[3]*Forum8*
[3]*yoann@forum8.co.jp*
[4]*Robert Gordon University*
[4]*a.bennadji@rgu.ac.uk*
[5,14]*Virginia Tech*
[5,14]*{ds22|thomasjt}@vt.edu*
[6]*Universita di Pisa*
[6]*paolo.fiamma@ing.unipi.it*
[7]*Osaka University*
[7]*fukuda@see.eng.osaka-u.ac.jp*
[8]*Harbin Institute of Technology (Shenzhen)*
[8]*skyduo@gmail.com*
[9]*New Jersey Institute of Technology*
[9]*narahara@njit.edu*
[10]*University of California, Santa Barbara*
[10]*marcos@mat.ucsb.edu*
[11]*University of Miami*
[11]*rron@miami.edu*
[12]*Georgia Tech*
[12]*matthew.swarts@design.gatech.edu*
[13]*Tongji University*
[13]*kostas.terzidis@yahoo.com*
[15]*Shenkar College of Engineering and Design*
[15]*rebekavital@gmail.com*

Abstract. Over the past 13 years, the 'World16'-group has collaborated face-to-face on various challenges that architectural design faces within VR, architecture, urban design, and its delivery to the professional industries. The focus of the collaboration is to foster pathways of academic research and developments to industries and professions. In

PROJECTIONS, Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2021, Volume 2, 203-212. © 2021 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

2020, due to the restrictions of the pandemic, the group had to rethink and redevelop how to collaborate meaningfully and become resilient: the World16 collaborated akin to the Virtual Design Studios (VDS) of the Nineties for the first time exclusively virtually becoming the 'Virtual World16'. The paper presents the group's various projects that are transformative to the praxis in VR architecture, design and urban design, and critically reflects on the lessons learned from VDS-paradigm.

Keywords. Virtual Design Studio (VDS); Human-Computer Interaction (HCI); VR, AR, XR; Collaboration; 3D City Modelling.

1. Introduction

The current academic framework of architectural research often thwarts Virtual Reality (VR) research and development. Most universities have only a few researchers in computational design, so it is not easy for them to find opportunities for development and collaboration. Conferences enable the sharing of conceptual knowledge, but not of VR technologies. Besides, there are many different VR instruments, so most researchers use different platforms to develop VR data and tools. As a result, it is difficult to verify each others' models, and it is hard to share a combination of knowledge and skills. It is a problem from the point of view of knowledge-accumulation (Kobayashi 2009). In particular, the collaboration and exchange with the industry and profession are challenging and often not well developed. World16 has set out to change this and actively connect internationally with researchers, industries in architecture, urban design, construction, and hard- and software developers who supply instruments for the field. Over the past years, there has been much development of VR-technologies, -modelling and -visualisations. The 'World16'-group has sixteen leading VR researchers (Stals and Caldas 2020) as permanent members on all continents matched by sixteen hard- and software developers. Additionally, adjunct members, guests-researcher or -practitioners offer fresh input to yearly changing research themes.

Since the modus of operandi of World16 is independently from research institutions, IP, methodologies and outcomes are shared openly. The close connection to industry partners offers World16 a timely grounding of their research and developments. World16 subsequently can operate in a unique realm that fosters novelty and transformative additionalities.

2. VR-Design Studio

Since 13 years, World16 uses and further develops the same common VR software platform *VR-Design Studio* (2020) to explore advances in city-modelling, VR visualisation, evaluation, narrative architecture, civil engineering, urban design, parametric modelling, computer graphics, digital art, and digital heritage. VR-Design Studio allows for a multitude of data types from industry-standard applications to be imported and simulated in a real-time 6D environment. The use of a common software platform enables World16 members to share data easily. Modification of the Software Development Kit (SDK) allows members to write their own computational tools when necessary. The Japanese software, developed around 2000 under the name *UC-win/Road,* can simulate traffic (moving agents), environmental conditions, and rich environmental data and visualisations in VR.

3. Virtual World16 Design Studio and Collaboration

In 2020, due to travel restrictions of the pandemic, World16 met for the first time exclusively virtually. First in July, for their annual 'hackathon' VR-symposium to co-develop, discuss and research novel avenues that can be implemented through VR-Design Studio. And again, in November, as part of the *14th Forum8's Design Festival 2020*, World16 showcased the outcomes of their research to industry- and sector-professionals at their yearly event, the (13th) *International VR Symposium* (F8DF 2020). Embracing the Virtual Design Studio (VDS) paradigm developed in the nineties (Kvan 2001), a 'Virtual *World16* Design Studio' (Vw16DS) was set up spanning over nine timezones from -13 UTC to +8 UTC. Three overlapping groups were set up to band members into most suitable time groups. Using the experiences gained by Schnabel and Kvan (2001) and Schnabel and Ham (2010) the Vw16DS worked and collaborated within an immersive social Virtual Environment (VE) to match the virtual realm of the research and development outcomes. Vw16DS used *Slack* (www.slack.com) as the main collaboration platform to facilitate collaboration, discussion and exchange. Video communication employed *Zoom* (www.zoom.us). Social- and dissemination-events were successfully held within *SpartialChat* (www.spatial.chat). Throughout the Vw16DS, various VR-plugins, -tools, -apps, and novel VEs such as *www.cluster.mu* were trialled, allowing to benchmark the research against recent developments in the field. Each symposia had at least two joint (virtual) activities for all group members, adjuncts and guest researchers to meet and critique their undertakings.

4. Virtual World16 Projects

The following twelve research projects were finalised in 2020, while others are still ongoing. They present a snapshot of the engagements of World16 over the past years. The research extends and builds upon the work presented in Kobayashi et al. (2010). Each of the research projects was led by one World16 academic who collaborated with one hard- or software developer. At the same time, the groups critiqued the work of each other at regular intervals to enrich the shared knowledge.

4.1. HUMAN-COMPUTER INTERACTION (HCI)

4.1.1. Eye-Tracking Voxel Environment Scultper (EVES)

Schnabel team's *Eye-Tracking Voxel Environment Scultper* (EVES) utilises eye-tracking to draw with one's eyes three-dimensionally within a VE (Wells et al. 2021). Within EVES, a ray is projected from the user's gaze data as the input method to sculpt voxels and navigate in-program menus. A guide-cursor follows the users' gaze indicating where they will sculpt. The guide-cursor takes the form of a selected brush, and by blinking - akin to a mouse click - voxels are sculpted and manipulated. Allowing eyes to draw, sculpt and manipulate form directly amplifies the capabilities of what the eyes can do, beyond that of which is typically possible. The eyes become actors in the design generation (Figure 1).

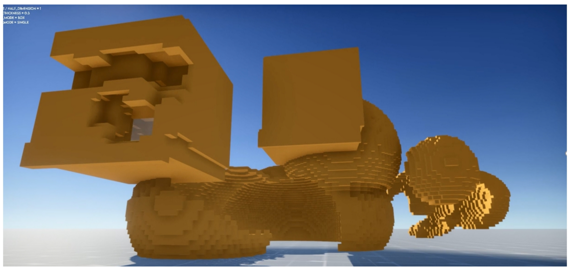

Figure 1. EVES' screenshot with Cube- and Box-tool as drawn with the user's eyes.

4.1.2. Interactive Mixed Reality Buildings

Tucker's project team utilizes physical scaled building forms overlayed with virtual reality. The interactive experience has the participant wear a *VIVE* head-mounted display (HMD) to engage with physical and VR buildings in real-time. The physical buildings have been modelled, and laser scanned to match the VR 3D buildings, so they are in sync when the participant grabs or moves a building form. To make the buildings interactive, VIVE Trackers have been placed on each building. Then the XYZ coordinates are fed into VR-Design Studio. The tracking is processed in the software to give real-time responses to movements and give responsive 3D visuals to the buildings' HMD participant in the VR space. The participant can manipulate both the physical and virtual objects and place them where desired (Figure 2).

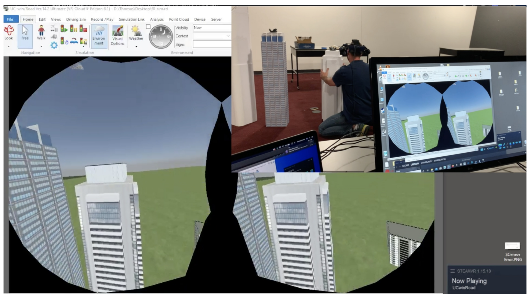

Figure 2. Interactive MR buildings, screenshot and physical models.

4.1.3. Interactive Virtual Sand Table (IVST)

VR has a highly simulated environment and efficient information interaction, pushing "human-computer interaction" to the level of "human-environment interaction". In participatory design, using this technology can reduce the operational burden of non-professionals and improve design efficiency. Lo team's IVST has a fixed viewing perspective. It duplicates the traditional physical sand table model and simply make it virtual and interactive. For non-professionals, it is easy to freely rotate the model and work with the virtual content by putting on 3D glasses and using hand gestures to manipulate the virtual objects intuitively (Lo and Gao 2020) (Figure 3).

Figure 3. System setting of the Interactive Virtual Sand Table (IVST).

4.2. VISUALIZATIONS TECHNIQUES

4.2.1. Point-Cloud Marker

Point-cloud data is useful for intermediate analysis within workflows, as they are relatively fast and contain attributes that model continuous data. Typical point-cloud colour data show either colour of the intensity value or actual RGB value if present; otherwise, it will be grayscale. To manipulate the colour of point cloud data is to reprocess each point cloud, save it out manually, and reimport into the point-cloud capable software, which is time-consuming and error-prone. Choi team's research altered this workflow by introducing a highlighting function. The area of interest in the point-cloud is changed by altering the existing or adding new colours to the data set via selecting the plane(s) in XYZ or boosting the current colour sets to a more prominent colour. The process allows for additional values and information to be added to the particular region (Figure 4).

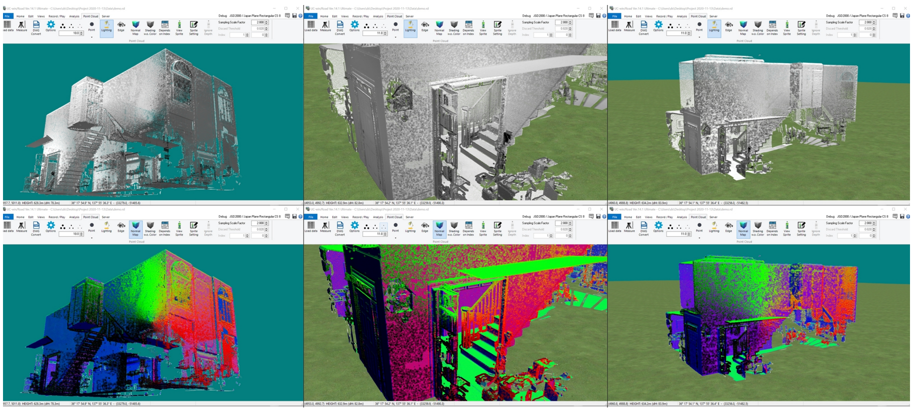

Figure 4. Screenshot of the Point-cloud Marker.

4.2.2. Motion Vector Visualization for Preventing VR Sickness

Increased uses of VR have resulted in a higher incidence of VR sickness. When a VR user along a predetermined walk-through path, audiences are forced to be presented with VR that involves movement and rotation. To prevent a VR sickness and ensure a VR content quality, a function is necessary to visualise movements within the VR space during the VR production process. Fukuda's team developed a rendering method of a VR camera's absolute velocity using a customised segmentation rendering (Fukuda et al. 2020). The absolute velocity values might be insufficient to evaluate a VR sickness. Their visualisation method of a VR camera's motion vector applies a customised segmentation rendering technique by calculating relative velocities on a VR screen at each frame. It overlays a colour on the screen according to the value to identify where in a virtual scene, VR sickness is likely to occur (Figure 5).

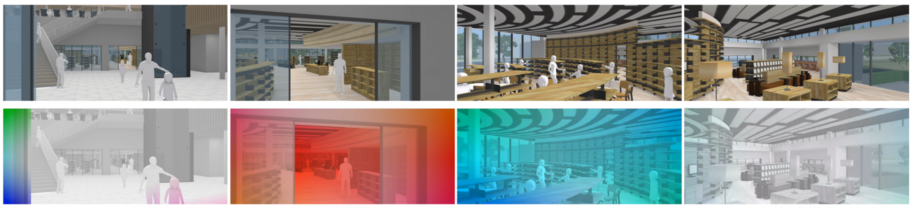

Figure 5. VR screenshots of motion vector visualization - normal and amended views.

4.2.3. Affordable Homes from Andragogy to Professional Tool

In collaboration with *Grampian Housing Association Ltd*, an affordable housing company, short design videos were produced. Due to the stakeholders' lack of interaction, a virtual self-guided exhibition was created to allow users to navigate virtually through the various designs. Bennadji's research team allowed future home buyers to understand better their home design and suggest changes they would like to see in their future home. Simultaneously, the transformative outcomes now allow housing procurement and commercial transactions to incorporate virtual procedures before a building is delivered to clients with higher satisfaction (Pleyers and Poncin 2020) (Figure 6).

Figure 6. Screenshot of one design of the Affordable Home Tool.

4.2.4. Artistic Interpretations of Point Clouds in VR

Vital's research team developed options for point cloud visualizations within the VR environment of VR-Design Studio. The visualization options go beyond the representation of points to points represented as different types of particles: i.e. brushstrokes, crystals, tiles, etc. and thus creating an artistic interpretation of the point cloud environments that can be experienced in VR (Figure 7).

Figure 7. Original point cloud and artistic interpretations (brushstrokes, hexagon particles).

4.2.5. Training of Tough Road Conditions for Drivers and Autonomous Systems

After developing solutions to simulate and visualise invisible urban environmental conditions (traffic noise, air pollution) (Grobman and Ron 2011),Ron's research team implemented into the driving-simulator the impact of reduced visibility (heavy rain, snow, fog (Figure 8), sandstorm, low sun angles) and increased stopping time/distance due to slippery roads conditions (wet, icy, oil-spill, unexpected obstacles). This included re-coding traffic algorithms to simulate car crashes.

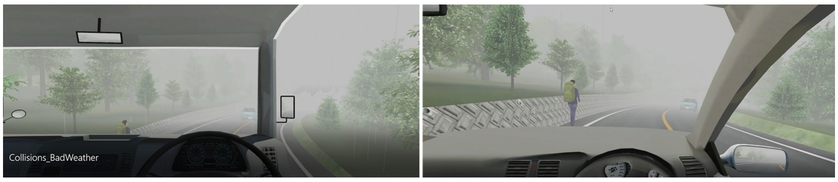

Figure 8. Simulation of a traffic collision in rain, fog and noise. Truck's and sedan's view.

4.3. INTELLIGENT MODELLING, DATA STRUCTURES, MACHINE LEARNING

4.3.1. Flexible Traffic Lights: Traffic Light Management using AI

Traffic lights are vital points of traffic managements as they can increase or decrease traffic flow depending on their timing. With the use of Artificial Intelligence (AI), it is possible to predict traffic flow. However, AI is often not transparent (a.k.a. 'black box'), stochastic, and therefore hard to rationalize (Lawe and Wang 2016). Terzidis' team constructed a system that uses permutations to optimize traffic lights' timing at intersections with AI prediction. It system replaces stochastic prediction with exhaustive permutations. Out of these permutations, patterns are sought that define the flow of traffic more accurately, making predictions more accurate, and impactful (Figure 9).

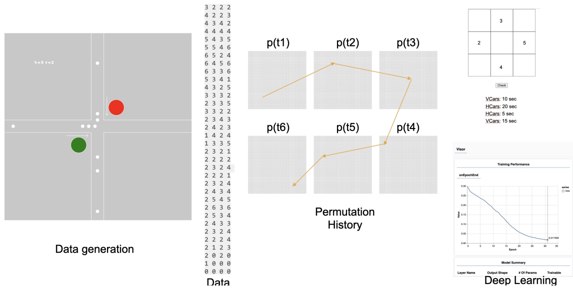

Figure 9. Flexible Traffic Lights System Map.

4.3.2. Recapturing Visions of Cities

VR is a time- and cost-effective pathway for data collection and annotating city images for machine learning (ML) (Narahara 2017). The acquisition of near-photo-realistic images and auto-generations of segmentation maps can be controlled by with ML algorithms rather than by web crawlers or costly outsourcing. Narahara's team used ML algorithms: images of various cities were extracted from VR models and used as data for the image-to-image translation model using *pix2pixHD*. Figure 10 shows examples of outputs transferred into "Tokyo style" from generic hand sketches with designated colours for some aspects of cityscapes as inputs. The use of larger datasets for higher quality and user studies are required to evaluate its feasibility.

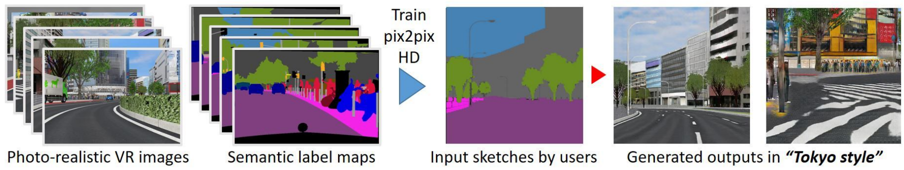

Figure 10. Sketches are transferred with selected cities' styles via datasets acquired in VR.

4.3.3. Selective Reality Substitution: 3D GAN and Latent Space Explorations

Autonomous vehicles, converging with XR, ML, AI, and HPC technologies, are enabling new possibilities for navigation through hyper-mediated urban spaces. Highly mediated environments are often boisterous and polluted by visual and spatial information. Just as sonic noise cancellation allows a focus on specific sonic signals, so can XR technologies replace undesirable aspects with other desirable visual and spatial information. Building on previous stages, Novak's research team explored how ML and AI techniques are used stereoscopically to generate alternate 3D *soft realities.* They are superimposed upon the real world to enable reliable *selective reality substitution* (transLAB 2020) (Figure 11).

Figure 11. Right: Picture of original space - Left: Soft Reality.

4.3.4. Designing sustainably using an IFC Parametric Development System

Fiamma's team combine data sets to IFC models and making these data and models parametric can combine different sets to a more sophisticated urban model. Akin to BIM, City Information Management (CIM) offers new lifecycle assessment pathways, design and planning. Parametric thinking means thinking about systems and subsystems, parts and entire, hierarchies of project and product. It leads actors to think (the construction design) like an organism made by connections (Fiamma 2014) (Figure 12). By bringing these CIM models into VR, diverse groups of stakeholders can understand the complexity of CIM and contribute to a process that responds to sustainability requirements (Venugopal et al. 2015).

Figure 12. Ontologies and parametric IFC objects as support to predittive design.

5. Conclusion

World16 has developed transformative research for and together with industry- and professional partners in the realm of XR in architecture, urban design, construction, heritage, city modelling, HCI, ML, and AI. In 2020 alone, World16 has innovatively collaborated in three main areas of HCI, visualisation, and intelligent modelling improving the simulation capabilities possible in XR. The professional virtual design collaboration - based on the VDS paradigm - between academia and industry has extended avenues to jointly advance virtual spatial simulations. The Vw16DS has evolved the VDS from an educational setting to a high-quality platform that intersects academic interests with those of the industry's and users' realms. Despite collaborating in real-time over several time zones is ambitious and challenging, World16 demonstrated successfully that the VDS paradigm can produce market-ready commercial solutions. The scheduled half-yearly touchpoints via joint symposia allowed all stakeholders to gain value from each other's developments, facilitated research validations, implementations, and dissemination to users. Over the next years, World16 will intersect XR with challenges of AI, blockchains, carbon neutrality, health and social-economical issues in the broader architectural and urban real and virtual realm.

Acknowledgement

World16 sincerely thanks the group of Forum8 software developer volunteers and acknowledges the financial support by Forum8 Co. Ltd.

References

"F8DF - 14th Forum8's Design Festival" : 2020. Available from <https://www.forum8.co.jp/fair/df/index-e.html> (accessed 1 December 2020).

"transLAB - Media Arts and Technology" : 2020. Available from <http://translab.mat.ucsb.edu/> (accessed 1 December 2020).

Fiamma, P.: 2014, About the Parametric Matter: is this [(x=x0 +at);(y=y0+bt)] Architecture?, *International conference on Innovative Engineering Technologies (ICIET'2014)*, Bangkok, 172-177.

Forum8, -: 2020, "VR-Design Studio" . Available from <https://www.forum8.com/technology/vr-design-studio/> (accessed 1 December 2020).

Fukuda, T., Novak, M., Fujii, H. and Pencreach, Y.: 2020, Virtual reality rendering methods for training deep learning, analysing landscapes, and preventing virtual reality sickness, *International Journal of Architectural Computing (IJAC)*, **18**(4), pgs 18.

Grobman, Y. and Ron, R.: 2011, Digital Form Finding: Generative Use of Simulation Processes by Architects in the Early Stages of the Design Process, *29th eCAADe*, Slovenia, 107-115.

Kobayashi, Y., Grasso, C. and McDearmon, M.J.: 2010, World16: Innovation and Collaboration in VR Technology, *Future Cities, 28th eCAADe Conference*, Zurich, 593-603.

Kobayashi, Y., Hawker, R., Terzidis, K., Narahara, T., Wael, A., Fukuda, T., Labarca, C., Calderon, C. and Jemtrud, M. 2009, World8: International Working Group for new Virtual Reality Applications in Architecture, *in* , *Joining Languages, Cultures and Visions: CAADFutures*, Les Presses de l'Université de Montréal, Montréal, 547- 556.

Kvan, T.: 2001, The Pedagogy of Virtual Design Studios, *Automation in Construction*, **10**(3), 345-353.

Lawe, S. and Wang, R. 2016, Optimization of Traffic Signals Using Deep Learning Neural Networks, *in* B. Kang and Q. Bai (eds.), *Australasian Joint Conference on Artificial Intelligence*, Springer, Cham, 403-415.

Lo, T.T. and Gao, X.R.: 2020, From HCI to HVRI - How different will the interaction of digital architecture design be?, *RE: Anthropocene, Design in the Age of Humans - 25th CAADRIA Conference*, Bangkok, Vol 2, 253-262.

Narahara, T.: 2017, Collective Construction Modeling and Machine Learning: Potential for Architectural Design, *ShoCK! - Sharing Computational Knowledge! - 35th eCAADe Conference - Volume 2*, Rome, 341-348.

Pleyers, G. and Poncin, I.: 2020, Non-Immersive Virtual Reality Technologies in Real Estate: How Customer Experience Drives Attitudes toward Properties and the Service Provider, *Journal of Retailing and Consumer Services*, **57**, 102175.

Schnabel, M.A. and Ham, J.J.: 2010, The Social Network Learning Cloud: Architectural Education for the 21st Century, *International Journal of Architectural Computing (IJAC)*, **12**(3), 225-242.

Schnabel, M.A. and Kvan, T.: 2001, Implementing The First Virtual Environment Design Studio, *Architectural Education for the Asian Century, 1st ACAE Conference on Architectural Education*, Singapore, 157-166.

Stals, A. and Caldas, L.: 2020, State of XR Research in Architecture with Focus on Professional Practice – A Systematic Literature Review, *Architectural Science Review*, **63**, pgs 9.

Venugopal, M., Eastman, C.M. and Teizer, J.: 2015, An ontology-based analysis of the industry foundation class schema for building information model exchanges, *Advanced Engineering Informatics*, **29**(4), 940-957.

Wells, C., Schnabel, M.A., Moleta, T. and Brown, A.: 2021, Beauty is in the Eye of the Beholder: Designing with One's Eyes, *Projections - 26th CAADRIA Conference*, Hong Kong, 10 pgs.