Experimental Applications of Virtual Reality in Design Education

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ABSTRACT

By introducing rapid reproduction, algorithms, and complex formal configurations, the digital era of architecture began a revolution. Architects incorporated the computational capacity of the computer into the design process both as a tool and as a critical component of the theories and practice of architecture as a whole. As we move into what has been coined “the second digital turn,” a period in which digital integration is considered ubiquitous, how can we consider, prepare, and propel towards the next technological innovation to significantly inform design thinking, representation, and manifestation? What tools are available to investigate this speculative design future and how can they be implemented?

If the integration of technology in architecture is now a given, perhaps the next digital design era is not just digital but virtual. As new technologies emerge the potential for integrating the virtual design world with our physical senses affords novel possibilities for interactive design, simulation, analysis and construction. Hybrid reality technologies, including virtual reality (VR) and augmented reality (AR), embody the potential to supersede conventional representation methodologies such as drawing, rendering, physical modeling, and animation. As they become increasingly pervasive, they will transform how we communicate ideas and data as spatial concepts. Further, they will reform the construct of the built environment when applied to both materiality and fabrication. This paper will describe the incorporation of VR as a tool in various classroom and laboratory settings, recognize the educational outcomes of this incorporation, and identify the potential relationship of these technologies to future academic exploration and application to practice.
INTRODUCTION

Video killed the radio star.

In 1981, MTV debuted with this ironically titled hit and initiated a cultural revolution by accommodating music as a multi-sensory experience. With the advent of new immersive mediums, is the conventional process of design and construction the radio star of our generation?

The proclamation that drawing is dead has been made and discounted so many times in the last decade that its potential for provocation has been rendered void. At this point, the formal experimentation coincident with the advent of computer processing speed, scripting, and three-dimensional modeling is so well-established within the discipline as to have become banal. In an age where animated rendering and building integrated modeling (BIM) standards are staple for corporate practice, the rebellious act of the cool kids of academia for the last ten years has been to amplify referential collage and drawing as design acts.

Mario Carpo calls the post-digital period that we are in now “the Second Digital Turn” and has identified that, despite the “technological nonchalance” of an architectural cohort he identifies as “PoDig”—those that are turning away from technology in search of attaining higher architectural principles using (ostensibly truer) analog means such as collage or drawing—are turning away from technology despite the fact that we are hurtling forward into an increasingly computationally-driven world inseparable from artificial intelligence, big data, and hybrid realities. In essence, “the post-digital will be even more digital” (Carpo 2018).

So what of the Post-Post-Digital? Is there such a thing? If algorithms and complex formal configurations were just the beginning of a revolution that began when designers embraced that there were some things that the computer could do better and faster than humans, how do we train new designers for a future that we cannot entirely predict but can only begin to see foreshadowed? Is the Post-Post-Digital actually virtual? How can contemporarily available tools for hybrid reality representation, including augmented reality (AR) and virtual reality (VR), be used to explore this speculative design future? How do these tools challenge our notions of representation, design process, fabrication and even materiality? What is the relationship between these new mediums and the production of architecture as a part of the built environment? The authors will describe the integration of VR in their own classroom and laboratory settings and identify the educational outcomes and the relationships to future academic exploration and applications to practice.

BACKGROUND

Like writers who use words to fabricate concepts in the mind of the reader, the designer has always operated in the realm of the virtual—using drawings, renderings, and models as a means to materialize ideas. Even a physical
construct, though it may be made of concrete, rise miles into the sky, and envelop thousands of cubic feet in volume, ultimately still aims to convey a larger architectural idea through form and material. Hence, architecture as a virtual condition has always existed. However, starting in the 1960s the consensus on the meaning of the term “virtual” began to shift as “virtual reality” began to emerge as multi-sensory expansion of stereoscopic glasses, even though the term wouldn’t be coined until 1987. Early VR explorations resulted in projects like Morton Heilig’s “Sensorama” or the first ever head-mounted display (HMD) that was too heavy to wear (Judd 2015).

The early 1990s saw VR gain popularity with the advent of immersive video games along with the movie The Lawnmower Man, which introduced many to the technology albeit in a strictly Hollywood mannerism. The Calibre Institute of Eindhoven University of Technology began implementing VR systems in design education during this time, and by their own admission, the low-quality of the available “transputer-based” system made it unusable for direct application in the practice of architecture. By 1999, however, they had six VR stations available to students and a list of completed academic projects which implemented the tools and technology as part of the design process, highlighting VR’s capacity for presenting lighting simulation and material options (Achten et al. 1999). Their prediction that virtual walkthroughs would ultimately be an output option for most software modeling tools has come true. The identified unrealized potentials and implications of VR as a design tool in 1999 are issues that the industry is still attempting to address two decades later, including simultaneous multi-user presence in the virtual environment, real-time dynamic modeling, three-dimensional data representation, in-environment design-aid tools, and accommodating a friendly user interface.

The obstacles to the growth and implementation of VR’s use in architecture, both practice and education, may be attributed to the difficulty of the tools, particularly for non-programmers and the expense of the equipment. In an effort to address these hindrances, some faculty turned to VRML for web viewing and desk caves as more accessible tools for students (Petric et al. 2001; Achten et al. 2004). A decade later, in 2013, the kickstarter funded company Oculus, created the Rift DK1 made vast strides in improving the head mounted display system for VR as well as making the equipment more developer friendly (Koles 2018.) And in 2015 the HTC Vive offered a full “room-scale experience” to users. This capacity offered consumer-level users the ability to walk, sit, and move-around at full-scale in both the physical and virtual environments. This deployment of a
consumer-friendly product revitalized waning interested in VR across many fields, and sparked a rise in the integration of VR as a tool in design studios across the world (Angulo et al. 2015; Dorta et al. 2016).

Previous implementations of VR in design education have varied in approach via method of integration, expectations, evaluation and equipment. VR use in a comprehensive design studio in 2013 suggested that VR augmented students’ creativity most when used in the last stages of design. This may be attributable to the limitations of the technology at the time or the difficulty/time-consumption of importing to VR from CAD-based modeling programs the students may have experienced (Abdelhameed 2011). Even with the delay between conception and visualization and the necessary abstraction that early VR required, spatial aspects of the design, like order and proportion, benefitted from the ability to “walk-through” the model (Campbell & Wells 2001). The evolution of the VR hardware and the software link it to digital modelling tools has greatly enhanced the experimental capacity of VR in the design process, and more recent design studio implementations have incorporated additional objectives or technologies such as agent-based modeling (Huang et al. 2018) and biometric feedback (Zhang et al. 2018). Examples below describe VR implementation as an expansion of the design process through conception, data visualization, and fabrication.

METHOD
The Authors have implemented VR technologies at two different universities in various points within the architectural education process in an attempt to address some of the unrealized potential of VR which the Calibre group identified. In particular, the Authors are interested in 1) the implications of using VR to communicate early design concepts, 2) the visualization of architectural data within the spatial construct of the virtual environment, 3) the application of the virtual user information into dynamically responsive systems, and 4) creating user interfaces for VR that support interactive communication and learning.

In each case, the implementation involves a head-mounted display device, hand controllers, and a physical space which allows the user to move at full-scale in the built environment. Long distance movements within the virtual environment, those larger than the physical play space allows, are facilitated through some other locomotion mechanism like teleportation or trackpad walking coordinated with the virtual model. This set-up is consistent with VR equipment produced by HTC as the Vive or VivePro and the Oculus Rift with touch controllers and motion / position sensors.

As the authors are interested in using the virtual tools as a means to interactively engage the act of representation of data and modification of the architectural model, the standardized output of software to a three-dimensional simulated environment was not sufficient for the experimentation. Modification of the software through the incorporation of plug-ins and programming allows a
control of the interaction with the environment, similar to how in gaming environments actions cause programmed reaction within the simulation. This is an important part of the idea that the virtual environment is not simply a new representation of the modeling data, but is instead a platform for design, analysis and the study of creating the physical built environment (Figure 2).

VR as a Conceptual Design Tool
Various methods for using VR as a design tool exists and have been explored in the academic environment (Angulo et al. 2015; Dorta et al. 2016). One method is to use 3D sketching programs like Google Tiltbrush to create rough 3D sketches which can then be exported out into conventional modeling software for further development. This method allows for full-scale design production, but still requires the user to translate the sketch digitally. The more commonly applied method is for the digital modeling to occur prior to export into a virtual environment and to be explored as a full-scale walkthrough. This method of modeling using VR for visualization allows for students to produce content using software that is typically familiar to them and reduces the learning curve of the VR integration. Software exists that allows for the direct connection between digital modeling programs and VR, and this is the generic manner in which most professional practices implement the technology. The value of VR as a representation tool using these direct connect methods is readily apparent, in that they allow for quick accessible immersive occupation of design conditions at full scale. However, the interface and interaction is a pre-programmed component of the software and the user experience is influenced or limited accordingly.

In the design studio described here, students were asked not only to consider the environments they were modeling using conventional 3D modeling tools but also the architectural potentials which VR as a medium could communicate even if the technological possibility was not readily available. Examples of such potentials include teleportation, anti-gravity, multi-directional elevators, and cyber-genetic augmentation. To facilitate the control of the user experience, the video game engine Unity3D was implemented. By incorporating the video game software as the host for the digital model students gained agency over choreographing the user interactions and were able to model non-normative spaces that were based on speculative architectural conditions like holodecks or the unconventional gravity precedent in the image below (Figures 3, 4).

Integration of VR in the early design stages of the studio as a conceptual design representation tool resulted in a notable improvement in the resolution of the project holistically. Instead of creating a singular, evocative image, design focus shifted to the experiential aspects. Where formal gymnastics have historically been the result of computer implementation in design, the use of VR intensified the consideration of scale, circulation, and view opportunities. Further, VR as a design tool encouraged students to design beyond conventional assumptions. Alternative materials
and responsive conditions are native to the immersive environment, and therefore it was almost natural for the students to conceive of their designs as interactive as well. This led to expanded application of kinetic, dynamic, and virtual materials as part of the students design palette. Multiple projects conceived of intelligent architecture capable of responding to human desires and commands and VR enabled effective communication of their design intent. One project allowed the user to speak to the room, for instance and the room would respond by transforming itself “physically” (Figures 5, 6). Students even augmented the audio and visual immersion by adding scented cues manually to the experience, for instance, wafting the smell of pizza at the VR user, when an architectural space was designed for food. Such attention to the multi-sensory conditions of the design product can be attributed to the early experiential exploration of the design that full-scale VR representation provides.

3.2 VR as a Data Visualization Tool

Expanding on the above methods, students taking a VR-centric professional elective titled “Mediated Environments” were asked to extend the digital model-to-VR methodology to incorporate architecture-centric environmental data produced via simulations- such as acoustics, daylighting, and ventilation. This additional step required that the students translate 2D software output, typically represented in plan or graphs, into 3D content for the VR model. Students primarily used height maps, extrusions, and floating points for spatial data visualization. These geometries were often simultaneously texture-mapped with the 2D images generated by the various simulation tools used to generate the initial data. Thus, the resulting visualizations incorporated multiple indicators intended to make the data legible (Figure 7).

Figure 8 shows a screenshot from a VR auditorium experience in which the user can toggle various performance criteria from any location within the building. Users can turn on and off furniture, acoustic enhancements, and the data visualization using a graphic user interface (GUI) accessed via a button on the hand controller. Selection changes made by the user result in both audial and visual feedback in the headset related to the acoustic behavior within the room. Other spatial translation methods required a more scripted approach to the data translation. Students utilized a C# based plugin written for Unity3D in order to convert into viable geometry from the comma separated spreadsheet data of XYZ and RGB values generated by a CFD simulation software (Figure 9).
Critiquing the readability of the incorporated data in the virtual model was a critical aspect of this exploration. Some spatial data translations were clearer than others, and the most successful utilized multiple indicators simultaneously—compounding scale, orientation, color, location, and direction. Because auditory input is a key aspect of the immersive experience, the data’s readability was further enhanced when audio components reinforced the visualization as well. Lastly, the user interface, typically a dashboard type pop-up menu was critical in supplementing the geometric components through instruction, legends, and explanatory text. Though vocal instruction can be easily created within Unity, students defaulted to visual instructions primarily, which may be indicative of the architecture students’ comfort with producing graphic content over sound. As immersive representation becomes more prevalent, architects, both student and professional, are likely to recognize the need to address the aural component of design directly.

3.3 VR in Assembly Analysis

The use of virtual reality as a tool for integrating technical capabilities and potentials into the design process was explored in the course Special Topics in Construction, a final studio in the Architectural Technology degree at the NYC College of Technology. This course emphasizes detailing and construction processes alongside of analysis and building systems coordination with a focus on the building envelope as a high-performance integrated system. Students are required to work on a building integrated model that is modeled in the same way that the building will be constructed, out of components of finite dimensions and specific connection necessities. For instance, the vertical run of steel columns in the assignment which is the design of a tall building, must be composed of steel structural sections built up and virtually “connected” in the model with the actionable dimensions and details that would be used in construction. This allowed the students to model not only the building geometrically, but to think about and design the building according to actual materials and construction processes and schedules. The incorporation of virtual reality headgear into the process allowed students to not only study in three dimensions the assembly of the components, but to sequence the construction through programmed animations to understand how the building would be built (Figures 10, 11). It is the authors’ belief that an understanding of the construction process is beneficial and is supported by the authors’ teaching experience, practice as well as published research (Anzalone et al. 2016, 2017).

3.4 VR in Architectural Research
The equipment and methods used within the student courses have simultaneously been tested through research projects produced by the authors at their institutions as experiential methods of visualization of sustainable building performance and as a tool for automation in architectural construction processes. In a professional practice and academic research collaboration, Bartosh has developed an interactive virtual version of a physical classroom lab to be constructed on a nature preserve outside Binghamton, NY. This VR project emphasizes the communication of sustainable design principles through the integration of data visualization methods developed for and during the Mediated Environments course. Daylighting, passive ventilation, and critical building systems information related to the building’s performance mechanically, acoustically, and materially are all represented spatially. Users can walk or teleport through the project and engage with the data by following the labels on the hand controllers (Figure 12).

Research in robotic automation in architectural construction at Professor Anzalone’s lab at the NYC College of Technology, specifically in the area of building envelope assemblies, incorporates VR technologies as a means to monitor conditions while AR is used as a control interface. Through collaborations with industry, the building envelope is explored as a site of not only the mediation between the inside and outside, the external representation of the building and designer, but also the location of design and construction activity and continued evolution throughout the life of the building. Automated assembly tools are being tested to explore methods to span the entire workflow process, where the virtual interface allows real-time monitoring and editing of the construction model, plans and processes as the system is assembled using the network of professionals, data and machinery to guide the process. Virtual reality technologies are used to monitor automated processes from remote locations while augmented reality technologies incorporate data and machinery control at the job-site to bring about a cyber-physical system of design and construction of the building envelope (Figure 13).

**OBSERVATIONS**

The authors propose that simulation and analysis cannot replace experience in the act of architectural design in academia, practice and research. And yet, as is commonly understood, the tools for design engage models of reality, where information is translated from the virtual to the actual built environment. We propose that these models are rich with potential to be a site of interactive, collaborative and multivalanced activity and that the interface provides the flexibility and control necessary to harness the inherent potential.

Contemporary software and technology allow designers to engage very complex tasks such as structural analysis while modeling, however, without experience with the conditions being designed, this power is not only illusionary, but could conceivably be disastrous. The same is true of designing, studying, and coordinating assembly through a virtual interface. We propose a parallel trajectory of utilizing virtual tools while simultaneously interacting with realistic materials, lighting, urban conditions, assemblies,
construction, data and so on. While this seems like a trivial conclusion, it can be seen that in drawing, drafting, rendering and animation, past education often allowed this disconnect to remain. Our argument is that the closer we get to simulating reality accurately, the more critical it becomes to be accurate about what reality really is.

CONCLUSION
The authors feel that virtual reality technologies, which have a long history in theory and experimentation in academia, have at this point become accessible in size, power and reliability of fundamental processors and software, as well as advances in components such as sensors, screens and other necessary hardware components, to the point of being available as a design tool. The importance of this topic is explored not as a mere next step in the standard visualization techniques, but as a fertile field for taking advantage of the capabilities afforded by the immersive and interactive virtual environment itself. By connecting to the physical built environment through data acquisition and analysis, control of automated industrial machinery, and collaboration of workers and researchers as well as artificial intelligence agents, the possibility of this new technology expands exponentially in multiple trajectories the possibilities of the designer to engage the creative and productive process.

FUTURE WORK
The authors plan to continue production within their specific studio courses with the intention of building up a deeper body of work and incorporating new equipment and processes. The research at the laboratories will benefit from the student work at the studio level, while incorporating and developing further advances in the fields and the work of the faculty. In order to begin to capitalize on the value of VR as a design, fabrication as well as a communication tool, the authors are planning a joint studio experience that will operate remotely across the two universities, allowing experimentation in multimodal means of design and production. The integration will be phased in such that the studios operate independently and yet are able to use information from the shared experience to increase the students and faculty understanding and expertise with the technology. Authors are further working with industry partners to explore implementation of VR design processes into the built environment through coordination, analysis and assembly projects.

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REFERENCES


IMAGE CREDITS

Figure 3-6: Images created by students of Syracuse University, co-instructed by Amber Bartosh and Brian Lonsway.

Figure 8, 9: Images created by students of Syracuse University, instructed by Amber Bartosh.

All other drawings and images by the authors.

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Phillip Anzalone is Associate Professor of Architectural Technology at the New York City College of Technology and a Principal of Atelier Architecture 64, a Brooklyn-based architecture firm with award-winning projects in North America and Europe. His research engages advanced structural systems, digital fabrication, facade systems and workflow processes. Phillip is a member of the Board of Directors of ACADIA, a member of the American Institute of Architects, and the Chair of the Professional Practice committee of the New York Center for Architecture. Phillip was a Technical Chair for the 2006 and 2018 ACADIA Conferences.