Design Instrumentation in an Immersive Virtual Environment

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Design representation and visualization are continually being reshaped by technology. Thanks in large part to the video game industry, Virtual Reality and Interactive Environments have become more accessible than ever before. At the same time, broad consumer exposure has been made possible by technical advancements that put Virtual Reality graphics on par with that of conventional video presentations. Much has been written about Virtual Reality insofar as its use as visualization tool, however there has been little research into the use of Virtual Reality as a design environment. This research examines the integration of Immersive Virtual Environments *(IVE)* in an architectural design workflow. Of particular interest to this research is the use of relatively inexpensive and commercially available Head Mounted Displays and controllers, paired with existing software, to test a design environment where sketching, modeling, and collaboration occur simultaneously in a 3D workspace.

From a pedagogical perspective there are several areas to consider with regard to designing within an immersive environment. Perhaps the most obvious difference is with regard to instrumentation. In this case we are generalizing the term in talking about the various things – ranging from a pencil to a computer mouse to a VR controller – we use to produce a graphic representation. Over time we have seen a shift, from the pencil and paper or computer's mouse and flat screen display, to more recent introduction of hand-held controllers or motion-detected gestural movements to create drawings and models. If we recognize instrumentation as a complex system, as components working together, we must analyze the entire system to understand how it impacts design thinking. This means viewing at the human body and its relationship to the 'design space' and 'design tools' together.

What, then, is important regarding the way design tools are used? In terms of instrumentation, the way we interface design tools and the graphics they produce impacts how we design. For example, holding a pencil and drawing on a piece of paper differs from dragging a computer mouse and clicking buttons. With a pencil and paper, in the *act of making*, there is a direct connection of the tool – or instrument – to the space where the image is visualized – the sheet of paper. With a computer mouse and screen there is a disconnect between the drawing instrument and space where the graphic is visualized. A pencil drawing on paper is always touching the paper when producing a line. In contrast, a computer mouse is physically removed from the surface where the drawing is visualized. As time has shown, it is not terribly hard for our coordination to overcome this when doing most tasks, however when it comes to actually sketching there is a problem. Not only is there a physical distance between the tool and drawing surface, there is also a reorientation of the drawing plane.

When drawing with a pencil and paper a single construction plane is engaged (let's define this in Cartesian terms as the XY plane). When using a computer *(fig.01)* mouse you draw on one surface - your mousepad is conventionally on the XY plane described earlier - while your screen is more or less perpendicular to it on what we might call the XZ plane. Perhaps more disorienting is the tool itself which no longer looks or feels like a pencil, rather an object designed to glide along a surface mimicking the surface of your computer screen. In terms of technology providing a solution to the first problem, the computer stylus has been able to reproduce the feel of the pencil-in-hand. The solution to the second problem has come in the form of an evolution of touch-screen capability. In both cases, the *act of making* in a digital environment required a more 'realistic' design sensibility to replicate the design environment used in sketching and other 2D applications.

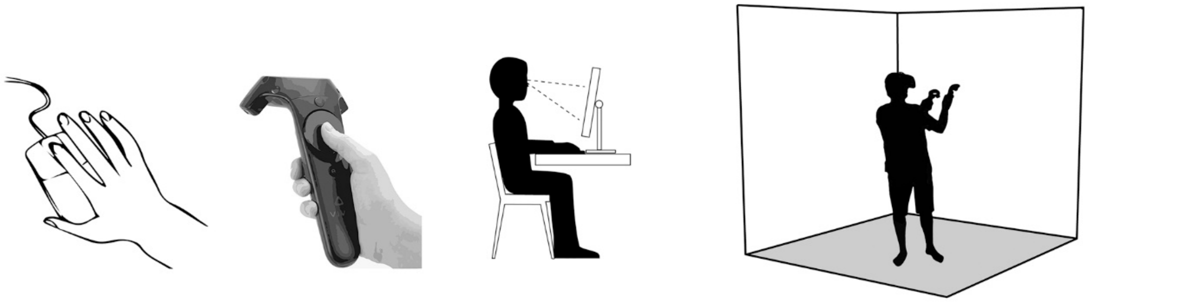

Figure 1 Left to right – Hand/Computer Mouse, Hand/VR Controller, Conventional desktop computer setup for modeling, VR modeling in open space

When it comes to three-dimensional spatial information there are different challenges. If we approach the *act of making,* in this case, as a purely an abstract matter of form-making – perhaps akin to the aforementioned two dimensional sketch – the conventional analog process might be sculpting. While sculpting there is a direct connection of the body to the object(s) being manipulated to realize form. Again, with the computer there has long been the problem of the mouse and screen *(fig.01)*, a disconnect between the hand and object being produced. But this time there are other problems with regard to the *act of making*. The digital model is represented on a flat screen in a way that it cannot easily be approached. In other words, while one can sculpt clay (or build any type of physical model) and immediately witness its three dimensionality in relation to the body, when working with a computer the digital model is always confined to the computer screen.

Figure 2 Hand sculpting with clay at left, sculpting in VR

An interesting aspect of an immersive virtual environment insofar as the *act of making* is concerned is that the hand-object connection returns to the digital modeling environment. In virtual reality, because the computer mouse is replaced by a controller that is recognized in 3D space, objects are produced at the precise location in space where the controller is located. To demonstrate this relationship we sculpted a simple clay model and then attempted to build the same model in an immersive virtual environment *(fig.02)*. In first making the clay model, students were able to record the procedures used to sculpt it into its form and attempt to replicate that using the virtual reality modeling tools. Students were able to digitally reproduce the same model using commands linked to controllers held in both hands. The process allowed them to make their models as if they were holding them in their hands. The experiment was an attempt to learn more about the similarities and differences of the perceived *hand-object* relationships – the 'feel' of making the model. While the tactile feedback of the modeling material was not present, the model itself *was* virtually present in the students' hands and could be repositioned as if they were picking up the model and moving it to another location in the room.

Additionally, we found the ability to scale the model in the immersive environment particularly useful. When creating a physical model one must first select a scale and the model will always exist at that size. The ability to scale a model in the virtual environment meant students could put themselves inside their designs, immediately giving them a sense of its proportional relationship to the body at a given size.

Having the ability to control the scale of a digital model relative to the human body in an active immersive environment brings us to another impact of *IVE, in* that orientation shifts from representing 3D space in a 2D environment *(paper, the computer screen)* to an actual volume of physical space as a work area. In turn, the characteristics of the workspace where making occurs have changed, bringing one's perception of their body's position in space into play as the body is now linked to the virtual modeling space.

To explain the impact of this in a design space, as the *act of making* it is useful to compare conventional digital modeling to modeling in virtual reality. In a conventional mouse and computer screen model the user is already disconnected from the object by having to view it through a screen *(fig.03)*. A user will typically draw with preset commands, immediately adding a level of certainty that may be undesirable. The user must have a knowledge of how the tool functions and will be limited to what it can produce.

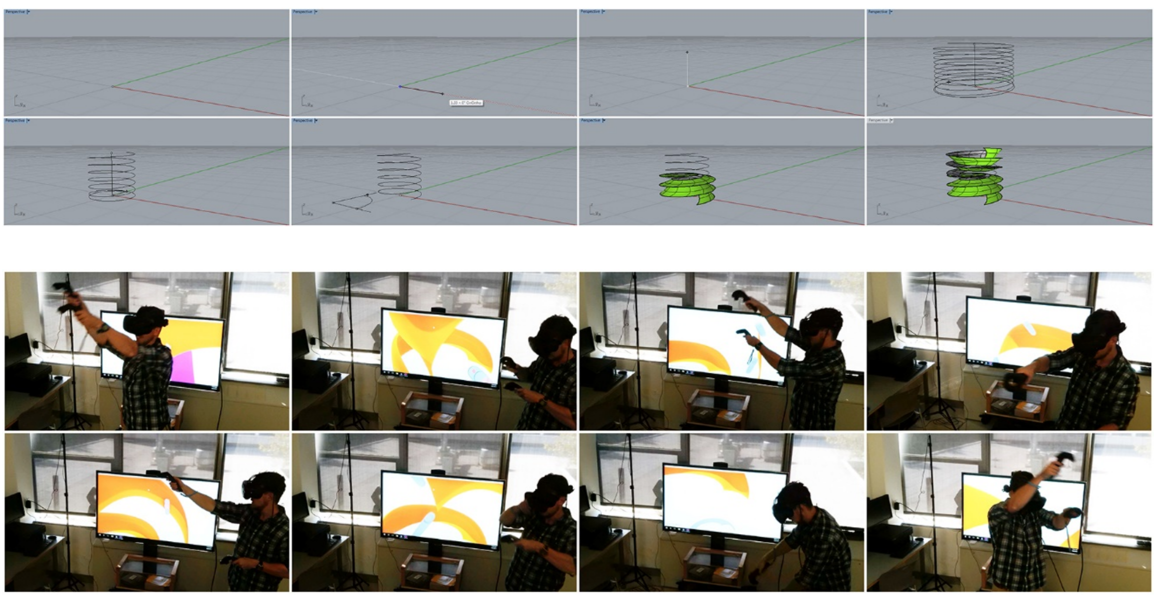

Figure 3 Top series – conventional process of making form with computer modeling using keyboard and mouse with commands. Bottom series – Making same form in VR using entire body; in this case by wrapping the form around the body.

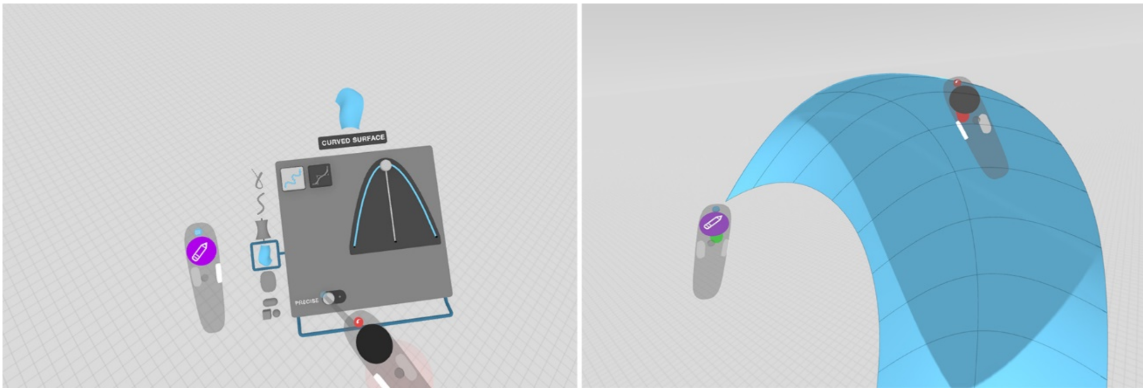

Figure 4 View user sees in Head Mounted Display. At left is the type of modeling tool used with variables available. Image to right shows both controllers being used as extension of arms to create form.

With virtual reality modeling there is an immediate perceptual impact of being *'in'* the modeling space. It is possible to model 1:1. This, combined with the freedom of movement of the body, allows one to draw in 360 degrees around their body *(fig.03)*. Designing oneself inside a model – rather than making objects at the size of a hand-held model as one would regularly do with a physical model due to material constraints - is a phenomenon we observed regularly occurring with new users. Being able to physically move through a design, as it is happening, means a different spatial perception. In surveys we conducted students overwhelmingly observed that they felt they better understood the 3D space in an immersive virtual environment when compared to viewing a physical scale model or digital model through a computer screen. Similarly, when is comes to designing, a result of gestural commands and intuitive control is that there is a close relationship with virtual objects and the tools used to create them *(fig.04)*. This direct connection of the body to form-making suggests a close relationship with physical modeling.

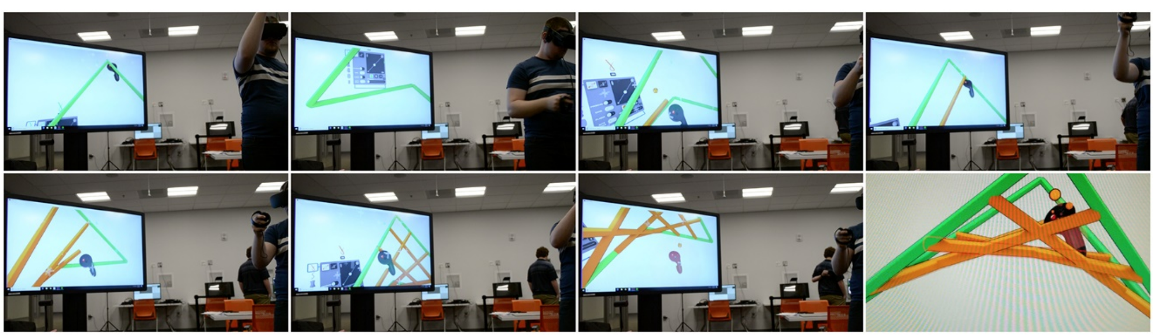

Figure 5 Procedural demonstration of making a ruled surface using VR.

Can virtual reality help convey spatial understanding in ways that 2D or 3D modeling struggle? We tested this by integrating immersive virtual modeling with a design studio project. The project is part of a series of short technical exercises given in a sophomore design studio that are meant to teach spatial design by demonstrating that there are computational processes behind the form-making they are engaged with. For the project students are asked to create ruled surfaces by first constructing them in an analog fashion, drawing two lines on a piece of paper. The lines are then divided into a series of points and the points connected between line one and line two in a series of straight lines, creating the illusion of a surface between the initial curves/lines. The intent is to explore 2D composition while offering a method for translating this into 3D space. Students later attempt to design a three dimensional physical model as a spatial composition inspired by the initial drawing.

Figure 6 Final student model of altered ruled surface.

The translation from 2D to 3D can be challenging for students, though, because the perceived depth in the drawing can be misleading. For some students using virtual reality as part of the design process, the shift to 3D was made easier by allowing them to construct a virtual model of their drawing in space *(fig.05)*. In this example the student was able to take the initial drawing into a virtual environment by making a rough digital sketch of its 3D form and later manipulate it considering material properties *(fig.06)*.

There are also implications with regard to design analysis. For example, it is possible to engage tactile feedback with regard to materiality, texture, shape, and other descriptors. To test this we combined physical mockups with a virtual environment to conduct a study investigating the impact of incorporating material feedback in a digital environment. In the study we modeled actual physical objects in the test space including a chair, a table, and two displays. We accurately positioned the physical objects in the room as they appear arranged in the virtual model. Rather than move and control the virtual space with handheld controllers, we asked participants to interact with the virtual objects with the VR headset on – meaning they could not see the physical objects *(fig.07)*. Participants were able to sit in the virtual chair and move it around. They could feel the table, the walls, the displays. On the displays were video recordings and on portions of the walls were samples of different materials they could touch while the virtual model changed the wall material to show what they were feeling.

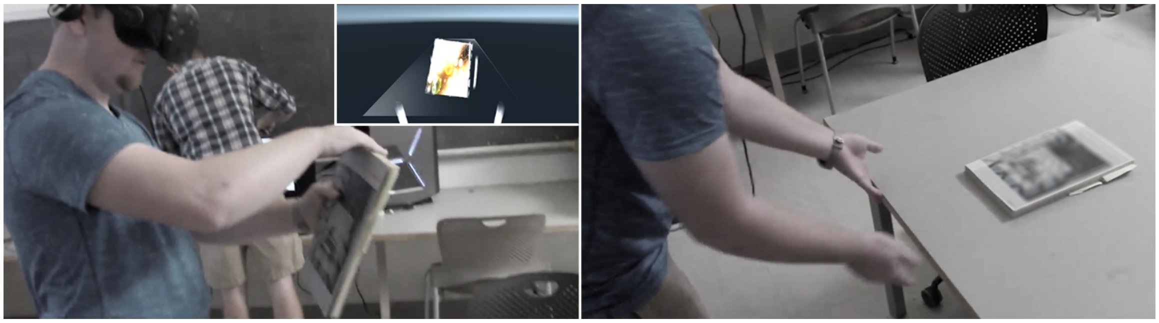

Figure 7 Tactile feedback with physical input. User holding book linked to VR model at left with inset showing what is visible in Head Mounted Display. At right, user interaction with table in VR.

In this study we observed a wide range of interaction ranging from what might be described as the comfortable user to what might be described as the cautious user. A comfortable user will navigate a virtual environment with little constraint, freely exploring and interacting with objects. A cautious user will struggle to interact with objects, feeling a level of uncertainty and discomfort with the environment.

Evidence from these studies and student interviews indicate that *IVE* have potential benefits as a teaching tool and an emerging design instrument. As immersive virtual environments become more commonplace we expect design instrumentation to play a larger role in design education. In the same way that a physical model cannot be the only means of architectural design exploration, virtual reality cannot be the only means of representing a design. Part of this study was aimed at learning how immersive virtual reality can best be used in a design setting. Based on our research, we feel virtual reality is:

- Very useful for understanding 1:1 space
- Very useful for conceptual designs
- Not as capable for detailed models
- Not as capable for a comprehensive design

Some additional general observations:

- For certain interactions a VR controller can be cumbersome
- For some people 'game time' is limited before needing a break
- VR very useful for spatial understanding of design (walkabout)
- VR very useful for user collaboration within an existing model

Future research aims to explore design workflows in more depth. In particular, there are currently limitations to this work environment that push design back to a traditional computer interface. While this change in work environment may always be necessary, we hope to explore how virtual environments can be better integrated into a digital design practice. Our main takeaway, though, is that the use of immersive virtual environments as a design space has been verified to have some measureable impact in the way students think about spatial design.