THE "NINE-SQUARE GRID" REVISITED: 9-CUBE VR - AN EXPLORATORY VIRTUAL REALITY INSTRUCTION TOOL FOR FOUNDATION STUDIOS

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Abstract. While the original Nine Square Grid problem, developed by John Hejduk and other influential educators, has shown many time-tested strengths; the value of the foundation studio project relies strongly on repetition and iteration. This activity oftentimes can be tedious when executed using traditional media. To expand upon the pedagogical goals of the original Nine Square Grid problem,we developed a virtual reality tool titled 'Nine Cube VR.' This tool expands upon the pedagogical goals of the original Nine Square Grid problem. Our tool takes advantage of immersive technology and its capacity to maximize object and spatial presence to aid in teaching beginning design students. Using the Unity game engine for development, zSpace Virtual/Augmented Reality desktop monitor and the HTC Vive head-mounted display, we created a multi-platform, easy-to-use kit-of-parts to educate beginning design students in architecture and interior design foundation design concepts.

Keywords. Virtual Reality; Architectural Education; Interaction.

1. Context & challenge of foundation design studios

As part of becoming an expert designer, novice architecture students learn the complex process of designing in a variety of ways (Cross, 2004). The development of an architectural or interior design project goes through a multifaceted and personal process that students have to develop and hone as they move through the design studio curriculum. Buildings and interior spaces are designed in an iterative manner that takes many types of knowledge, experience, and sensibility to do well.

The modern architect is expected to be fluent in both digital and analog modes of creation and visual communication. Students can create, visualize, evaluate and iterate through the design process with many tools that they have at their disposal. Sketches, physical models, hand drafting and various digital tools aid in the externalization of ideas. Additionally, timing is an essential factor in which ideas must be expressed immediately to a client, to an instructor or oneself, allowing the process to flow naturally towards completion. In foundation studios, students enter a learning environment in which their core competencies are developed in preparation for more advanced design projects. Foundation studios usually

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focus on introducing 3-dimensional composition, development of a sense of scale, graphical representation, and visual communication skills. Foundation studios are often more structured than advanced studios in the design curriculum to let students focus on select aspects of architectural design while excluding others to keep the challenges manageable.

1.1. TECHNOLOGY AND DESIGN EDUCATION

Technology plays a supporting role in a designer's toolkit. The most cutting-edge software and hardware in-and-of-themselves do nothing without a designer making decisions with an objective. In the same way, computer-aided design (CAD) tools, 3D modeling, and rendering are not very different from sketching and illustrating because they support and facilitate the communication and evaluation of ideas. Sketching isn't the final product of design in the same sense that a 3D model isn't - they play primarily a supporting role as visualization aids that facilitate the entire creative process.

Architecture firms are quickly adapting to the latest construction, simulation and visualization technologies to stay competitive in the ever-growing global design market. When educating a design student in the 21st century, it is essential that we prepare students for this technological reality. Many design schools today employ computer numerical control (CNC) routers and 3D printers in their fabrication laboratories. Energy modeling tools, climate simulation software, and GIS are part of most computer labs as well.

Virtual Reality (VR) has now become affordable and is being embraced by the design industry for its capacity to accurately visualize physical buildings at a human scale. Clients are also demanding it because this technology lets them experience future spaces relatively inexpensively while giving them a strong feeling of being present and immersed within their project. VR thus allows them to make more educated, executive design decisions and suggestions to the designers. Virtual Reality is also used in a multitude of fields for training and assessment primarily for of its capacity to mimic and control realism parameters freely. These disciplines utilize VR for its excellent ability to simulate spaces and objects to increase the sense of presence better than previous technology and media. In VR, researchers also get the benefit of being able to measure, track, and customize controlled experiences while being able to collect performance data for further analysis (Sun et al. 2017; Indraprastha & Shinozaki 2012).

1.2. FOUNDATION STUDIOS AND THE "NINE SQUARE GRID" EXERCISE

Many different pedagogical techniques help design students grasp the different facets of the design process. We can trace many exercises common now in foundation design studios to those developed in the early 1970s by a group of influential design educators such as John Hejduk. These exercises are effective in introducing students to various aspects of the design process. Hejduk's (1987) famous "Nine Square Grid" is among them. Hejduk's exercise focuses on the syntactical and linguistic aspects of design (Sehgal, 2015). It provides a limited set of parts (or "kit of parts") and a variable program for students to follow. It gives students a limited kit of parts with several constraints on transformations and dimensions to maximize pedagogical goals related to composition, form, and representation without overwhelming them. Within these constraints, instructors are free to adapt and modify the focus of the exercise and better target their instructional goals. The capacity of the student to innovate within a limited context also makes this exercise suitable to introduce core concepts of design. The problems that students must solve in these exercises teach them about the fundamental aspects of design. They also begin to comprehend the relationship between 3-dimensional form and 2-dimensional projections through drawings and physical models.

The “Nine Square Grid” and similar exercises are often explored using traditional media such as physical models and hand drawings. Students make models out of wood blocks and rubber cement. While this approach has many strengths, it has two significant limitations. While the value of foundation projects depends on repetition and iteration (Kuhn, 2001), these exercises are tedious when executed using traditional media. A student’s effort is more on model-making than on ideation. Also, it is not easy for students to absorb the idea that these smaller scale representations are abstractions of architectural form and space that one experiences in real-scale. Thanks to the success of this traditional and adaptable pedagogical tool, there have been previous attempts at replicating it as well as incorporating technology into these exercises.

1.3. POTENTIAL OF DIGITAL TOOLS IN FOUNDATION STUDIO

Kalisperis and Pehlivanidou-Liakata (1998) have shown that digital tools are helpful for 3-dimensional visualization and can result in more design alternatives under time constraints. Yazar and Pakdil (2009) initially developed a digital version of the nine-square problem. Their tool nGrid consisted of a MAXScript application which allowed the student to design within the 3D Studio Max software under constraints like Hejduk’s (1985) assignment. The authors found the tool useful in allowing students to explore multiple design ideas, more than they would have if they used a real kit of parts. However, nGrid has a few limitations in our observation:

- The learning curve involved in learning 3D Studio Max for a beginning design student is high.
- The tool’s screen-based, 2-dimensional, mouse and keyboard interaction limits natural interaction.
- The inability to explore designs in an immersive environment to truly test 3-dimensional composition and experience.

We propose an easy-to-use virtual reality toolkit which introduces to beginning design students without needing 3D modeling skills or use of CAD software. Our approach offers an intuitive submersion into the world of iterative design, form-making, and spatial thinking. Our Nine Cube VR “kit of parts” presents a constrained, 3-dimensional design composition problem to teach syntactical and spatial relationships through iterative exploration. The Nine Cube VR digital toolkit enhances ‘spatial presence,’ invites exploration with an intuitive interface for interaction and introduces the student to architectural representations, especially orthographic projections.

1.4. PRESENCE

If a critical goal of architecture is to shape human experience through the interactive exploration of space, then the pedagogical tools should facilitate developing skills for that. It is essential therefore to talk about spatial presence, a concept borrowed from media psychology. Lombard and Ditton define presence as “the perceptual illusion of non-mediation” (Lombard & Ditton, 2006), which means that one perceives the mediated experience as reality instead of their immediate physical environment. In the design process, students experience varying degrees of spatial presence depending on the media they use (i.e., physical modeling vs. virtual reality). Different media and different representational techniques differ in their affordances for enhancing spatial presence. Floor plans and schematic drawings serve organizational planning. Other types of representations such as perspective drawings and renderings afford an increased experiential view of a design. Large screen displays and virtual reality that provides a wider field of view and stereoscopy give a more immersive experience and enhance the sense of spatial presence. Early experiments in integrating virtual reality as part of the design studio (e.g. Kalisperis et al., 2002; Otto et al., 2003) have been received well by the students and continue to gain traction as these technologies become increasingly immersive.

Educators and educational technology designers can improve both the learning experience as well as the learning outcome by enhancing spatial presence. Improved spatial presence achieved through increased interactivity and stereoscopy - like those found in modern VR systems has great potential for teaching more nuanced spatial skills when educating beginning design students with digital tools (Wang & Kim 2009; Liao 2017). We believe that we can enhance spatial presence in architectural education tools by maximizing affordances for interactivity which then increases a student’s possibilities for action in the environment under design. Similarly, stereoscopy immerses a student in their proposed design and provides a compelling visual experience and enhances their sense of ‘being there.’ Virtual reality can overcome the gap that exists between traditional methods of representing space and the pedagogical goals related to the real space they are designing.

2. Nine Cube VR

This paper presents the Nine Cube VR, a digital tool intended for early studio education that builds on the original nine-square grid problem. This digital tool takes advantage of the innovations in stereoscopic 3D displays and interactive input devices while retaining the positive qualities of the original nine-square grid exercise which uses traditional media. Our development process for Nine Cube VR digital application started with a detailed needs assessment and underwent multiple iterations of technology development and usability testing. The Nine Cube VR application can be deployed across two virtual reality displays: zSpace

(zspace.com), an interactive, stereoscopic desktop monitor and stylus with six degrees of freedom and a head-mounted headset (HTC Vive) with positional tracking. The primary development platform for the application across both display devices was the Unity game engine and its built-in scripting environment. It was used for the scripting of all necessary interactive components, the user-interface interaction and design and implementation of intended pedagogical concepts. Figure 1 shows the stereoscopic 3D display of zSpace used by the student to create a digital model with a limited kit of parts. The composition space is limited to a constrained, 9x9x9 bounding box. Figure 2 shows a student experiencing and navigating through the same model in a 1:1, real-world scale using the HTC Vive VR display. Figure 5 shows two designs going through development in zSpace, followed by the assessment of spatial experience with the HTC Vive and finally, to a completed physical model.

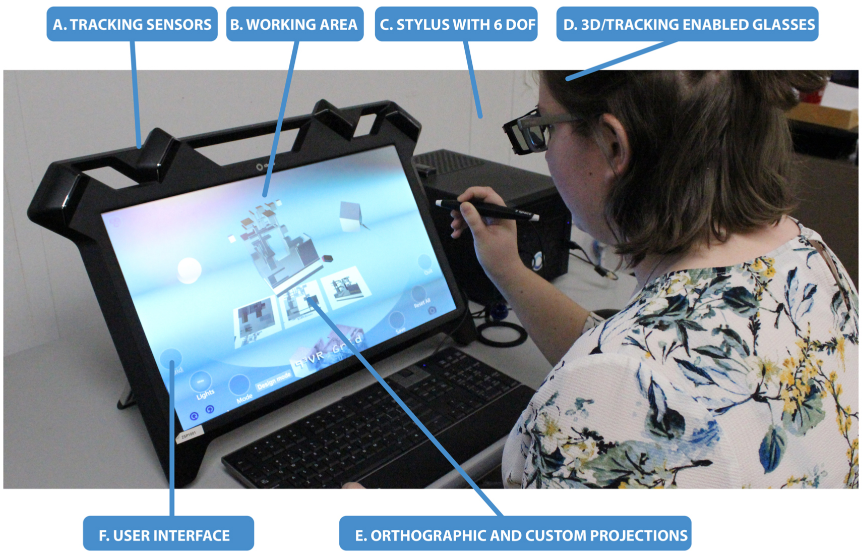

Figure 1. Student creating composition in stereoscopic, interactive environment.

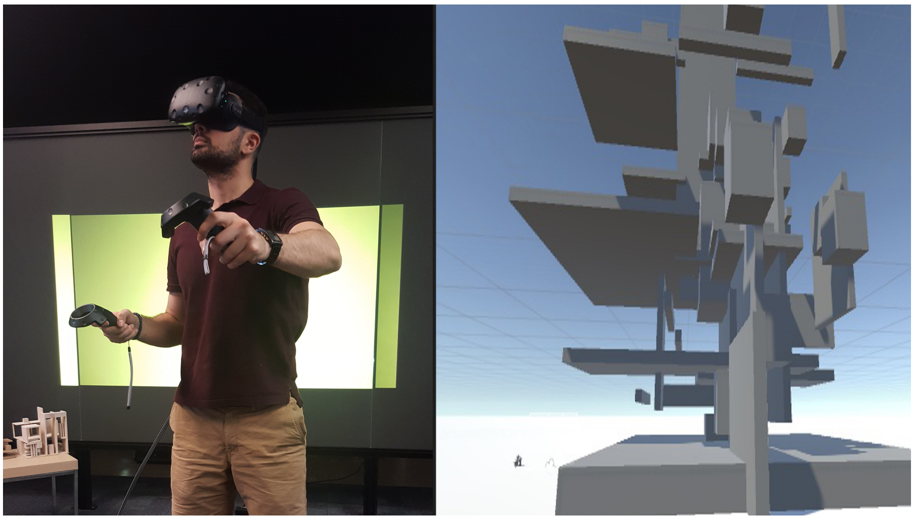

Figure 2. Student interacting with environment in real-world scale.

2.1. DESIGN FEATURES AND USER INTERACTION IN NINE CUBE VR

The user interaction with the kit-of-parts in Nine Cube VR is straightforward with six degrees of freedom on both the zSpace (using a stylus) and HTC Vive VR (using handheld controllers) systems. This stylus allows the user to interact with 3D objects in a way that closely resembles how one naturally manipulates an object in real life. A simple user interface with logical icons and toggle switches is located in the bottom of the screen and visible at all times (Figures 3,4). The predetermined components come from the original Nine Square Grid kit and are built into the system. Students design with the kit components from the start, and do not spend unnecessary time creating the component pieces by themselves from scratch. The composition area can function as a 3-dimensional, grid-based, orthogonal space where the pieces snap into place or can be toggled to a free-form design mode without constraints or boundaries. Once an individual component is placed within the design environment, a student can use keyboard shortcuts to fine-tune its location and orientation. The bounding grid can be hidden or shown in order to visualize the extents of the permissible design space. Multiple views(plan, elevation and custom perspective) can be customized and toggled to introduce conventions of architectural representation as the design process evolves. Furthermore, the stereoscopic display with head tracking enables one to experience the model from the first-person point of view at all times. Additionally, the Nine Cube VR system lets the student experiment with an interactive light whose position and color can be changed. This feature provides the learner with the ability to experiment with color and additive light. More importantly, the finalized model iteration can be saved and loaded onto the immersive environment that the HTC Vive provides. This model can then be experienced at a full architectural scale (Figure 2).

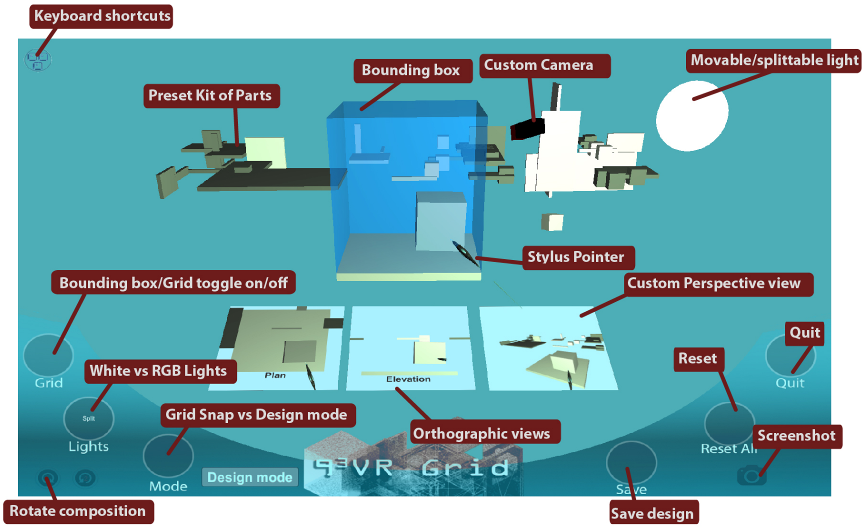

Figure 3. Nine Cube VR screenshot with feature labels.

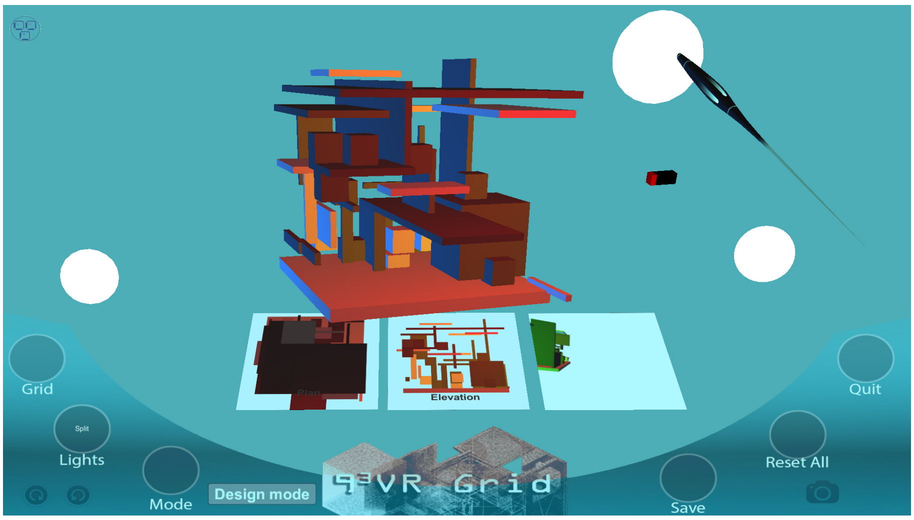

Figure 4. Working model showing split RGB lighting experimentation.

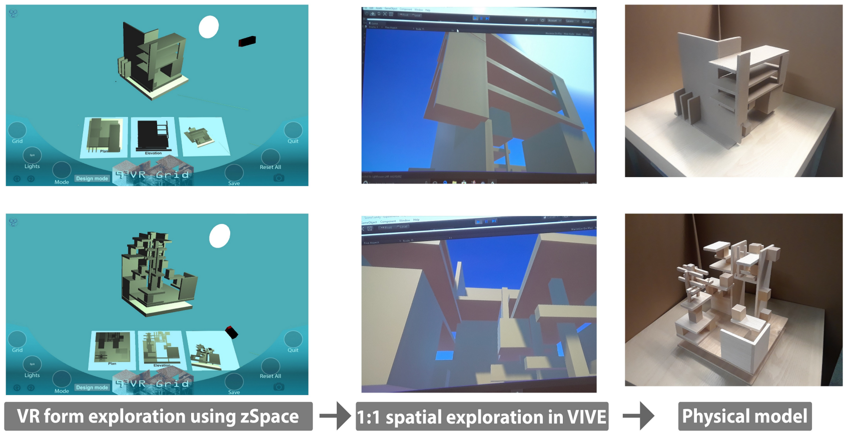

Figure 5. Process from zSpace to HTC Vive to physical model.

3. Usability feedback and future work

Initial feedback from studio instructors and students were positive, pointing to the tool's good potential for improving student's design skills. We are further refining this tool and are currently in the process of integrating it with our foundation studio curriculum. The application demonstrated its usefulness for creating a variety of design alternatives rapidly in an intuitive fashion. It is also a valuable means for teaching lighting concepts, orthographic projections, and ideas of architectural representations without the necessity of learning complex 3D modeling programs. In future versions, we will incorporate drawing and sketching tools, for example, perspective grids, and silhouette mode for contour drawing exercises to further teach students quick prototyping and evaluation techniques with the aid of modern technology. On the immersive environment space, we plan on incorporating 3-dimensional sketching, multiple actor interactions, collaborative options and the implementation of building information modeling concepts in the early stages of design. The user interface can be further optimized and improved in future versions to integrate gestural interaction. Also, currently all parts are predetermined and non-modifiable. Future versions can include customizable sets that the instructor can give to students to meet various pedagogical goals as it was originally intended in Hejduk's "kit of parts."

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