# Virtual Reality/Space Visualization in Design Education: The VR-Desktop Initiative

KALISPERIS Loukas N., OTTO George, MURAMOTO Katsu, GUNDRUM Jack S., MASTERS Raymon, ORLAND Brian

The Pennsylvania State University, USA
http://viz.cac.psu.edu/vr/html/sala_cac_lab.html

*Although virtual reality (VR) is a fast-growing field, utilization of its potential within an affordable environment in the early years of architectural education has been limited. Currently, we are in the process of exploring the educational potential of virtual reality in the creation and understanding of space as a set of dynamic volumes that can be experienced. The VR-Desktop initiative is an effort to bring the salient features of projection-based VR to second-year architecture students in a way that is more generally accessible than the many canonical, first-generation, projection-based VR systems. The VR-Desktop has been implemented in the teaching of the architectural design studio in the second year of a five-year curriculum, as part of the physical architectural studio. Through the VR-Desktop system in the studio, students immediately start working in an immersive environment. They create space by manipulating solids and voids while evaluating the anthropometric relations of the proposed solution. The students are able to study and test conceptual details in a virtual environment from the very beginning of their architectural design project.*

*In order to assess student perception of the usefulness of various system attributes for diverse tasks, we have begun a usability study. Thirty-five surveys were collected from the students who had used the lab during the two semesters for which the two-screen system was available. Preliminary observations indicate that within the architectural context, virtual reality techniques involving depth perception can convey relevant information to students more efficiently and with less misrepresentation than traditional techniques. This paper suggests that full field of view, motion, stereoscopic vision, and interactivity are possible components of the 3D visualization techniques that are necessary to enhance architectural education*

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## Designing space

One reason that it is difficult for students to understand and visualize space is because the traditional graphic media used to represent and manipulate space throughout the design process are limited. Traditional media are static images that cannot represent the effects of movement and change over time in terms of light and motion. The two-dimensional static image produced by traditional graphic methods is inadequate as it can only express the quality of a space at one point in time and from one point of view. Visualization that includes movement

and time sequence allows designers to make better judgments about space and form. Lifelike simulations give the opportunity to experience mistakes before they are constructed and to learn from them. Computer hardware and software have been developed that are capable of creating a virtual reality that will allow designers to model, articulate, and animate movement through the design process. They have the potential to allow a designer to simulate three-dimensional forms and motion with a high degree of accuracy and detail.

This research seeks to integrate virtual reality into the discipline in order to generate processes and results that are impossible without computers – to go beyond simple automation of existing procedures to use new technology to extend the design process.

## Virtual space

Virtual reality has the potential to improve the quality of architectural representation. It is utilized in diverse areas of study, including cognitive mapping and planning. These uses can inform our understanding of the benefits of virtual reality in architecture.

As scholars who study cognitive mapping note, people are frequently required to move in an unfamiliar environment. As a result, researchers such as Albert *et al.* (1999), are particularly interested in how humans navigate and acquire spatial information about real environments. One problem in the design of experiments is that manipulating the structure of a real environment is difficult or even impossible. Virtual reality creates the opportunity to simulate, as well as control, the layout of the environment. According to Hillis (2001), virtual reality has numerous advantages over traditional presentation methods because "it permits the creation of environments of varying complexity and allows interactive navigation with continuous measures within it." In recent research on cognitive mapping and virtual reality, Albert (1999) controlled which feature of an environment to present at a given time. He also

allowed the subjects to observe the environment from a previously selected viewpoint. These methods permitted the analysis of the experimental data in a more detailed and accurate manner, not possible utilizing a real environment. Albert's work demonstrated that the research subjects were able to learn the desktop virtual environment using various viewing conditions accurately in a short amount of time.

In studies involving planning research it was established that the utilization of virtual reality has great potential as it also involves the use of spatial data. As suggested by Orford (1999) virtual reality could provide an "accurate means of reviewing design guidelines, whether proposed or in place, and might offer the prospect of significantly opening up planning process to public view that previously would have been restricted to professionals."

Mallot and Gillner (1998, 2000) have pointed out the advantages of using virtual reality in behavioral experiments, because of both the ability to control computer graphics stimuli and the easy access to behavioral data, such as the subject's movement decisions, enhances research. Mallot and Gillner found that knowledge of configurations could be acquired in virtual environments, in spite of the fact that the subjects were interacting with a computer graphics simulation and did not themselves actually move.

Virtual reality 3D visualization in architecture deals essentially with volume conceptualization. Traditional 2D architectural representation is capable only of depicting aerial or planar concepts and implies a spatial dimension only when these concepts are used in series. By merging motion with computer-aided 3D visualization techniques, spatial concepts can be easily conveyed. Such spatial information, when delivered through proper apparatus, can simulate depth—one of the most important components of spatial cognition. In addition, other architecturally related concepts such as shadow studies, transparent underlay, and form morphing,

which were generally unavailable through traditional drawings, can now be represented in a manner easily understood by students.

## The Virtual studio

In our architectural program only one of our goals is to familiarize students with the generally accepted body of knowledge regarding the computer and how it is used in architectural practice. We also believe that design education should aspire to go beyond convention and search for new ideas and strategies. We are in the process of developing a new pedagogical model that emphasizes design process and theory, which allows students to approach architecture as a knowledge-based discipline. It encourages students to be venturesome and discover innovative solutions by exploring more alternatives and designing from a holistic standpoint. Students are encouraged to design in three dimensions from the beginning of conceptualization. Through simulation and testing of the building design, students go beyond convention and explore movement in both time and space. The virtual reality visualization techniques allow the students to understand space and form, as well as texture, contrast, and color, as they explore spatial and temporal movement.

Although virtual reality is a fast-growing field in other areas, in architecture no one has attempted to utilize its great potential within an affordable environment in the early years of architectural education. The need is especially great in these years, because it could change the student designer from being simply an observer through conventions to being a participant. Through virtual reality, the student designers can explore the proposed space; they can immerse themselves in the space in a manner similar to the way in which it would be used.

Currently we are in the process, through a joint project with the Information Technology Services, of exploring the educational potential of virtual reality in the creation and understanding of space as a set of dynamic volumes that can be experienced. The ITS's VR-Desktop initiative, as implemented in the Immersive Environments Lab, is an effort to bring the salient features of projection-based VR to second-year architecture students in a way that is more generally accessible than the many canonical, first-generation, projection-based VR systems. We refer to this goal as "lowering the bar and extending the reach" for the use of VR in everyday teaching and learning.

Projection-based VR systems have been around for about a decade. From the initial and somewhat prototypical efforts of the early 1990s, these costly, albeit very high-performance, systems have evolved to offer increasingly useful and durable designs for the high performance research community within which they typically are deployed. Van Dam *et al.* (2000) opined that immersive virtual reality remained in a "primitive state of development and is very expensive and therefore not in widespread use." It seems that this assessment still holds true at the time of this writing. Projection-based VR still is not in common use beyond a very select group, mostly drawn from the high-performance research community. We believe that the lack of acceptance by general users is due to a dearth of richly-featured, discipline-specific, VR-enabled applications to which such users can easily transition; a challenging programming environment for non-programmers who would attempt to use VR systems to develop unique applications; and the typically high cost of purchasing and maintaining such facilities. Our experience has been that for many potential users in a university community, the effort and resources required to bring VR techniques to on everyday research and teaching have been too great.

The design point for the VR-Desktop is to provide systems that meet a wider range of potential users closer to "where they are" in terms of existing computing skills/work methods, budgets, and physical proximity. The objective is to make the VR environment as easy, cost effective, and convenient for users to realize the benefits "big screen VR" can

bring to their disciplines and organizations. The principal design points in building our system were: 1) maintaining affordable cost by using "commodity" components; 2) offering ease of use by employing familiar computing environment (Windows) and support for applications with which the students are familiar (e.g. FormZ); and 3) allowing seven-day, twenty-four-hour access by students, in proximity to their existing studio space.

## The VR platform

At the time of this writing, and for the usage period assessed with student surveys discussed below, the Immersive Environments Lab display system included two six-by-eight-foot, rear-projection, passive-stereo, display screens. The screens are joined at the middle and positioned at a 120-degree angle, providing a sixteen-foot panoramic view when used in dual screen "VR" mode.

The initial and primary architectural application for the VR-desktop is the Navigational Loader (NavLoader) program, which is written almost entirely in Java. NavLoader allows design students to load, display in stereo, and navigate VRML97 models created in FormZ or other applications of the students' choosing. A joystick provides the primary navigational input for the current implementation, and as currently used is dependent on the Windows operating system and associated device drivers. We have implemented earlier variants of the NavLoader under other operating systems (*e.g.* Solaris and IRIX) using devices independent of specific operating systems, such as the SpaceOrb. These system-independent devices are controlled using the Java communications API, whereas the system-dependent devices use the Java Native Interface (JNI) to communicate with the native operating system.

Java3D, an extension to the Java platform, is the basis of the application. Java3D utilizes the underlying graphics API to do the actual rendering. We are using the OpenGL implementation for Windows. The high-end graphics cards that we use (*e.g.* 3Dlabs

Wildcat) to produce the quad-buffer stereo image are inherently designed for OpenGL hardware acceleration. The stereo image produced is frame-sequential stereo that normally requires drawing at a monitor refresh rate of 100-120 Hz. Our systems use a CyViz xpo.2 stereo converter to split the frame sequential stereo signal from the graphics card into separate projection signals for the left and right eyes, for projecting passive stereo images with two projectors per screen, one each for the left-and right-eye views. Since the resulting images for both eyes are continuously projected, rather than sequentially interleaved as with frame-sequential active stereo displays, the monitor refresh rate can be reduced to 60 Hz, without introducing noticeable flicker. The lower refresh rate allows for a greater choice of monitor resolutions and utilization of commodity LCD projectors.

The two eight-by-six-foot screens are positioned in a wedge that is offset from the typical flat screen at the middle by 30 degrees (see Figures 1 and 2). This offset produces a feeling of immersion in the 3D space when both screens are projected with stereo images. To create separate viewing frustums for each screen a Java3D View Object is created with two Canvas3D Objects attached to it, one for each screen. The Canvas3D Objects each have an associated Screen3D Object containing an image plate, which can be configured to match the physical positions of the screens. In the Java3D View model space, screen positions are defined relative to a fixed frame of reference in the physical world by the tracker base. The tracker base is used to define a fixed frame of reference, even if no physical tracking hardware is being used. Coexistence coordinates provide a frame of reference that can be defined by the user in the manner that is most convenient for positioning the physical configuration of the image plates, the tracking hardware, and the eye positions in the virtual world. The Java3D renderer then performs the projection of the virtual world onto the physical display surfaces automatically.
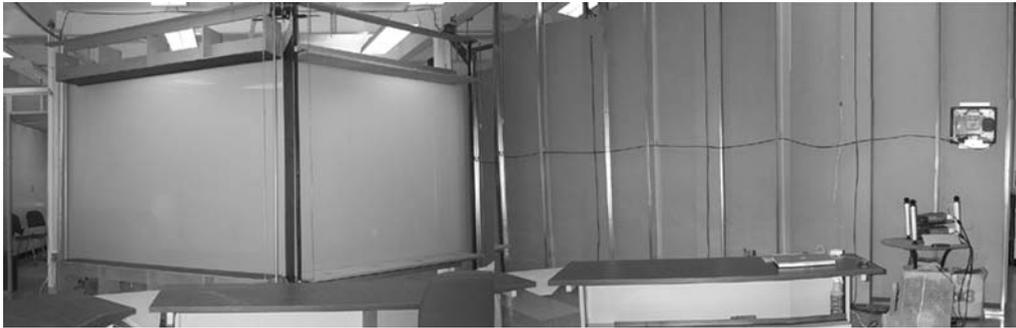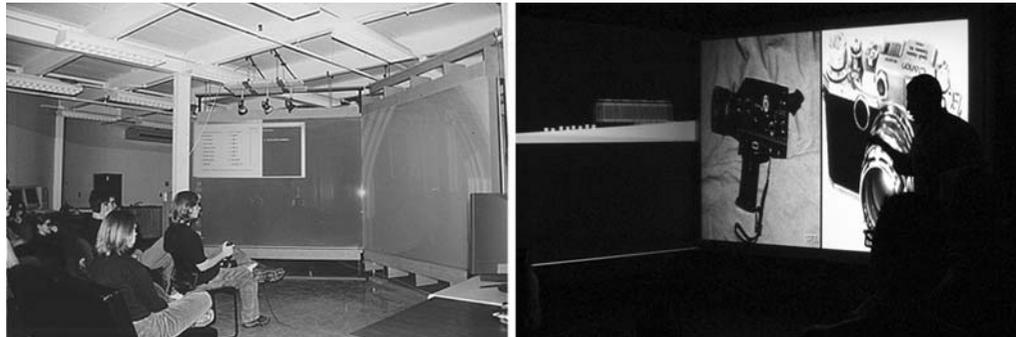
The NavLoader program works by first loading a VRML file and parsing that file to obtain the scene graph information. The ability to load the full VRML97 specification is in the beta-testing stage under the Xj3D project (Web3D Consortium: 2002) and will be implemented in future versions of NavLoader when the final code is released. The scene graph is then traversed to load in the views created in FormZ and then saved as VRML View nodes.

## Implementation of VR simulation in a second-year design studio

Over the last three semesters (five design rotations of seven-and-a-half weeks each), an equal component of our design studios introduced students to the use of computers in enhancing design possibilities. Students spent one-half of each semester using the VR-Desktop environment to design their projects

as part of the normal rotation through four different instructors. The projects were not specific to the fifteen-student computer studio: they were the same assignments as for the other three sections of second-year. This program involved approximately thirty-five students, from the second-year design studios, during the three semesters. Integration of computers directly into the design studio took place in a physical environment that united the traditional drafting table with the VR-Desktop environment.

Through the use of digital design media, 3D modeling, and virtual reality, students in the studio developed a critical design sense of fundamental architectural form, systems, and vocabularies. They examined the relationship between order and idea and developed their analytical and design capabilities through this exploration of digital technology.

The undergraduate architecture design students

provide a nearly ideal user community for the development of more accessible VR tools. For the most part, the students are not advanced users or programmers, so the design point for any tools deployed needs to be straightforward and in keeping with existing workflow. The students' design work is such that the potential benefits of the human-scale interaction with their designs are readily apparent. The resulting independence and enthusiasm of the student users and the feedback they provide on software development have been invaluable in our success.

## System implementation and evaluation

Through the VR-Desktop environment in the studio, students immediately start working in a VR environment. They create space by manipulating solids and voids while evaluating the anthropometric relations of the proposed solution. The students are able to study and test conceptual details in an immersive environment from the very beginning of the project, increasing the creativity and success of their designs.

The designers of the Immersive Environments Lab (IEL) system initially envisioned its use as a surround screen or immersive 3D environment for use in individual design development and personal visualization of models, something along the lines of a "poor man's" CAVE[tm]. The students, however, quickly adopted the system for use as a multi-modal presentation space, in addition to its use as the personal and immersive system that we envisioned. For example, the students often use programs such as Microsoft PowerPoint on one screen, in conjunction with stereoscopic 3D presentation on the other. Due to the familiar desktop computing environment employed, several students have been able to identify useful software additions for the system, such as stereoscopic multimedia tools, and communicate their applicability to other users, thereby enhancing the usefulness of the lab and increasing the quality of work for everyone. Examples of student work pro-

duced by the design studios using the new visualization technology are used to illustrate the success of this studio. (See Figure 3)

To better assess student perception of the usefulness of the diverse system attributes for the variety of tasks undertaken, we have begun a usability study. This work is ongoing and will be reported periodically as the design of the lab evolves and new user communities, application areas, and usage patterns emerge. Thirty-five surveys were collected from the undergraduate students who used the lab during the first semester for which the two-screen system was available. Thirteen surveys were completed by students enrolled in second-year architectural design studio. Nineteen were from students enrolled in an undergraduate studio in Digital Design Media. And three were from fifth-year thesis students who had independently chosen to work in the facility. The surveys were similar in content except that studio and thesis students were asked a series of questions regarding use of the system for "architectural design" development and presentation, whereas the digital design media students were asked the same with regard to "artistic and digital media" development and presentation. The resulting survey data will be reported at greater length in a separate paper now in development by the authors; however, some preliminary observations are worth mentioning here.

One of the questions the students were asked was the open-ended question, "Please describe three aspects of using the Immersive Environments Lab that you felt were most convenient, useful or successful in your work." Specific functional or formal attributes that most often were cited as beneficial were stereoscopic or 3D projection (17), large screen size (15), and the ability to navigate and/or view the scene from different viewpoints (13). Several students specifically commented on psychological dimensions, such as "you can envision being in your project" or the "ability to show others what you see in your imagination." It would seem

*Figure 3. Beyond the tool –
Integrating the physical and
the virtual*

that initially, at least, that the utility of the key VR ingredients of wide field of view, stereoscopic projection, and interactivity have been validated by the students. Student responses often discriminated between useful functionality of the system and the awkward implementation of the same. For example, several students positively commented on "the ability to move around the scene," while at the same time mentioning that system response made navigation awkward for large models or that they did not like using the joystick to do so (which the authors suspect is confounded with poor system response for large models, which contributes to the difficulty in navigating with the joystick). Several comments pertained to access and spatial layout of the facility. For example, the convenient, unattended, and twenty-four-hour access was cited as a plus, as was useful presentation space, whereas limited audience capacity was cited as a drawback. Such observations should be useful for sorting out where best to focus future efforts to improve system functionality, room layout, scheduling, and other concerns that will influence acceptance by users.

Issues surrounding the design and acceptance by users of VR systems are inherently subtle and multifaceted. Over time the authors should be able to report on the evolution of multi-modal and interdisciplinary use of the lab, perhaps shedding further light on the opportunities of various system configurations for various tasks as evidenced by their adoption, or lack thereof, by our student users

## Conclusion

Within the architectural context, virtual reality techniques involving depth perception can convey relevant information to students more efficiently and with less misrepresentation than traditional techniques. This paper suggests that full field of view, stereoscopic display, interactivity, and motion through the scene are possible components of the 3D visualization techniques necessary to enhance architectural education.

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