Theme:

Title: **Interaction in virtual building space**

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Abstract: *This paper presents the results from two experiments in working on descriptions of form in immersive virtual environments (IVE). Recently, Virtual Environments (VE) are increasingly used as environments for design and research. Using VE to visualize ideas from the initial steps of design, the architect is challenged to deal with perception of space, solid and void, without translations to and from a two dimensional media. From this new ability, we might expect new forms of design interaction and expression. The goal of our studies was to identify how designers use and communicate early design ideas by using immersive three-dimensional (3D) VEs and how they describe 3D volumes using different media. We set-up a series of experiments including navigation- and perception-tasks, designing in IVE, transcription of design, remote communication between design partners and controlled observations. We explored initial intentions of 3D-immersive design schemes, textual descriptions and collaborations within IVE. This paper describes the outcome of creation, interpretation and communication of architectural design, by using an Immersive Joint Design Studio, as well as the description and translation of a 3D cubic structure. We discuss frameworks and factors influencing how architectural students communicate their proposals in an immersive Virtual Environment Design Studio (VeDS), and how this approach of design studio enables to understand volumes and spatial relationships.*

Keywords: *Virtual environment, remote collaboration, design evaluation, spatial understanding*

1. Introduction

Architectural Design is increasingly influenced by Virtual Environments (VE) (Bertol, 1997). Not only equipment and software become available and affordable for common users but also designers recognize VE as a tool of form-finding (Leach, 2002). However, research on the outcome of results and its possibilities of architectural design within VE is still in progress (Stuart, 1996) and lessons learned from academic contexts have already been employed in commercial settings. Architectural design teaching uses the method of Virtual Design Studios (VDS) as a common mean of instruction. While some have been successful, various issues have been reported, for example a lack of communication and collaboration (Kvan, 2000); technology overhead (Kruijff, 1998); and potential contributions to design outcomes. Immersive-VE (IVE) has not been used for design interaction, although shared immersive virtual spaces have been employed for design reviews (Davidson, et al. 1996). The next step is, to establish joint design sessions where users can collaboratively create, interpret and communicate design ideas within an immersive Virtual Environment Design Studio (VeDS) and to examine if this context offers any new opportunities or solutions to problems encountered. This exercise resulted in conceptual descriptions of space; the results suggested further work needed to be done in clarifying just how well three-dimensional (3D) form was understood in IVE. The second experiment followed the first to engage students in describing forms they examined in IVE.

2. The Virtual Environment Design Studio

VE offers and challenges the architect to deal with perception of solid and void, navigation and function, without translations to and from a two-dimensional (2D) media (Campbell, 1996) in order to envision ideas. The goal of our studies was to identify how architects use and communicate design ideas by using IVEs.

2.1 Experiment

To investigate the context of a VE, we sought tasks that engaged designers at a variety of levels of complexity: the design of a commercial helicopter landing station in an urban setting. This task required users to work in three dimensions at all times yet could be abstracted to reduce representational problems. The helipad is a typical architectural task rife with complexities of functional needs (sight lines, access, form, etc.) yet also very much a 3D question. This experiment including navigation- and perception challenges was conducted with remote communication between design partners and controlled observations permitting transcription of design. That allows comparison of the results with earlier experiments (Kvan, 2000).

The VeDS aimed beyond the initial idea of a VDS by introducing new dimensions to the participants. Firstly we wanted to see if a virtual studio could be run in an immersive environment. Secondly, we wanted to see if the use of immersive virtual reality-design-systems shifted design and its communication to a different mode or level. It has been suggested, for example, that participants in a VE might express and communicate their intentions, ideas and designs not only in a different but also in an improved manner (Dorta & LaLande, 1998). We hypothesized that the VeDS would have a positive impact on the development of design, its communication and understanding.

This experiment builds upon virtual studios in which the *Department of Architecture* at *The University of Hong Kong* participated since several years (Bradford, et al. 1994; Kvan, et al. 2000). Teams on the either ends worked together on the very same design task. It is a short exercise, which finishes within a single day. In short and frequent intervals the remote partner exchange design ideas, proposals and modifications, which reminded us of a ping-pong match. Each side had the authority (not ownership) over parts of the design. This co-ordination is necessary in order not to obstruct the team partner's activity. A typical collaborative scenario where architects and specialists contribute to an overall scheme in sequential and parallel activities is simulated with this set-up (Kvan 2000).

Comparable to brainstorming and concept finding activities, the studio focused on the initial stages of design; elaborated final designs were not the intension of the exercise. Comparable to a moderated verbal discussion in which the microphone is passed to speakers, the Head Mounted Display (HMD) was passed between the teams and the resultant design sketches were produced within the IVE in the course of the alternating sessions. Text communication was provided in order to support the design process. Since we wanted to capture the intent of the design, we used a modified "think aloud" methodology. We established a design team of two at each end, one wearing the HMD while the other taking notes and chatting with the remote team to convey the intent of the design in writing. These text records provided a protocol, which is analysed later on.

Many issues and obstacles have to be addressed. Collaboration and co-ordination, technical matters of bandwidth, file transfers and communication, have to be addressed as well as tuning of equipment, ensuring equal opportunities for participants and the availability of facilities. In this design studio, both ends employed the same configurations of immersive virtual reality (VR) equipment: a Pentium III computer with broadband internet connection, Flat-screen monitor, *Kaiser Proview 60 HMD*, *Polhemus Fastrak* magnetic tracking device and a *Stylus*. The *Virtual Reality Architectural Modeller* (VRAM) developed by Regenbrecht, et al. (2000) had been modified and equipped with input features based on gesture-recognition. Similar as the input-system for PDA-devices, the users now gesture with the stylus and their movements are translated into basic 3D primitives (Figure 1). A second PC was used for the communication using *ICQ*-Software, Internet-browser *(IE)*, Web-based database and other presentation-software (*AutoDesk 3DStudio VIZ* and *Adobe Photoshop*).

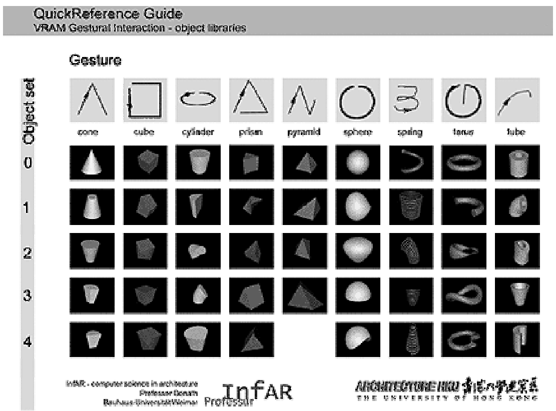


Figure 1: Gesture Reference Guide

For our experiment it was pre-requisite that the participating students acquired both a broad training in IT (through CAAD- and DTP-software) as well as an advanced background in architectural design.

The intent was to engage the students in rapid design exploration, which was completed in one continuous cycle. Each design-phase (called *ping* or *pong*) was set to 30 minutes during which one team had control over the model. Each 'ping' or 'pong' was finished by file-exchange and fine-tuning/adjustment of equipment. The teams placed their models and chat conversations into a database (modelled on Hirschberg, et al. 1999). This database holds a short presentation explaining design intentions and achievements of each ping/pong. The remote team then continued to work on that model in order to complete their phase. After four exchanges the VeDS concluded with a final presentation and live video-conference.

Using this sequence, a complete cycle of VeDS was finished within four hours and was repeated in order to accommodate eighteen groups in total. A final critique was arranged at the end in which all teams came together presenting their work to each other, instructors and external examiners in order to debrief the teams and discuss the different outcomes and the new approach to architectural design.

2.2 Results

Most notably, we successfully demonstrated that it is possible to design, communicate and collaborate in IVEs. The eighteen teams did engage in collaborative work, building at each ping/pong on the work of the team partners and own preceding steps, despite the technical complexity of the system and the difficulty of working remotely together.

Next, participants noted in the chat-line communications that their designs surprised participants in their creativity and appearance. Obviously students experienced and translated their ideas differently from non-immersive environments. They stated that the interaction within IVE was direct, that each stroke had an immediate impact on the design and acts as a 'shortcut' from idea to creation. The students had the impression that they could 'communicate' directly with their model, became part of it and lost the otherwise typical distance of a designer. They reported that this led to very different forms and new arrangements in their design.

Further, collaboration was possible. We anticipated that the teamwork may not interact smoothly with each other, which occurred in earlier VDS. However, the opposite was true. The teams engaged in intense discussions about design, concepts and form assisted by the nature of the task and application. In order to pursue their schemes further the groups had to communicate their actions to the remote partners. However, participants developed a personal interest to share their experience and creation with their colleagues and other member of the teams.

As mentioned above, the intention of the experiment was to use IVE as a tool to create and communicate design as part of a whole design-process. This VeDS served as base for further exploration and development of the design-task. The outcomes are therefore only slices of a more wide-ranging progress and not mend to be wholly elaborated and finalized schemes. The results act as visual communication tool of its meaning and are only initial exploration of the participants' intensions.

Initial reviews of the graphic outcomes advocate that the students used the space actively within all three dimensions. Spatial clusters were created to represent design elements at all aspects within the available design area. Typically, an architectural design created in a 2D representation would have placed components in plan-view with some raised in section/elevation to achieve 3D volumes. However, in this VeDS, the students started 'sketching' their design elements at any points within the 3D sphere. Observation during the VeDS showed that participants did not use a particular method to design, such as floor by floor, function defines form or form defines function. Being virtually inside their design, they sculpted their proposals, making use of the flexibility of viewpoints offered in VE. They investigate the spatial impact of their design in relationship to existing forms and activities from outside and at the same time within the model (Figure 2). Though the technical constrains the input systems were crude and clumsy, users rapidly learned to represent their design intent by using the cubes and spheres as representational volumes (Figure 3). Since these primitives can symbolize both positive and negative representations of space, other viewers of the model, were able to understand this ambiguity easily (Figure 4). In some cases, because of lack of experience or the complexity of this VE, errors or coincidences were transformed into expressive architecture (Figure 5), a behaviour observed in 2D design environments as well. Other instances demonstrate that students were inspired by their own 3D model and translated their design back to a (mental) image (Figure 6). Differences in design- and operation-skills as well as architectural language can also be identified (Figure 7).

Figure 2: Users are involved (in terms of scale, viewpoint and navigation): design that uses the flexibility of VE, offers to explore structure and its spatial impacts on the creations (Playground, VeDS104)

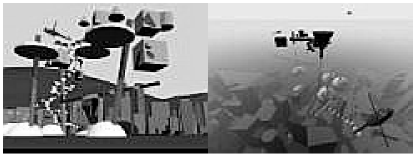


Figure 3: Primitives representing functions or forms, independently of their actual 3D shape (HeliPad, VeDS110, Phase 3 - 4)

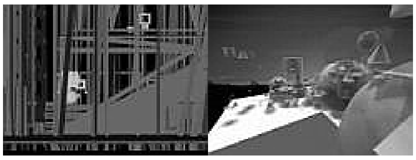


Figure 4: Primitives can symbolize both positive and negative representations of design-elements, remaining interpretable by viewers of the model (HeliPad, VeDS108, Phase 3; Playground, VeDS112)

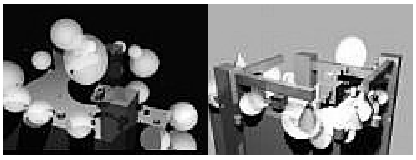


Figure 5: Lack of experiences or complexity of the VE, created errors, which are transformed into 'meaningful' architecture (Playground, VeDS103)

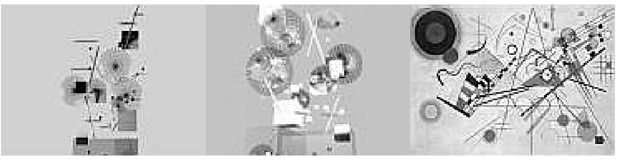


Figure 6: Plan and perspective of design with an image by Kandinsky as mental inspiration - image added later by student (Playground, VeDS106).

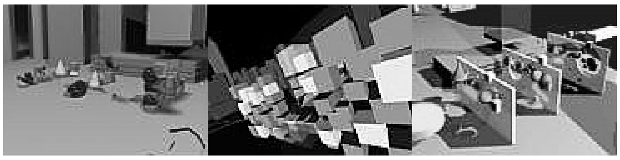


Figure 7: Differences in design- and operation-skills as well as architectural language can also be observed (HeliPad, VeD106, Phase 2-4)

Examining the chat-conversations between the teams we anticipated a large number of navigation/orientation discussions and explanations of meaning of placed elements. Surprisingly, the texts show only a few lines of such conversations. This suggests that participants could find their way without much difficulty and work with the IVE-interface. Students were able to understand and extract the intent behind the design-scheme of the remote partner easily. The complete documentation of this VeDS (2001) can be viewed online at http://courses.arch.hku.hk/vds/veds01/db.

The text records do not identify how or why the students were using the 3D space in these different ways. However, we do find evidence of intense discussion about design, functions and concepts. Students engaged in design discussion and development of the scheme by referring to the model they saw in database, submitted by their remote team-colleagues. Since the designs are modelled using simple geometries and it is not clear, if the students had a better understanding of 3D form in an in VE than they would have in traditional 2D paper or screen-based scenario. A second set of experiments was therefore mounted to investigate this specific aspect.

3. The Cube

For the purposes of a particular experiment, we interpreted an abstract architectural spatial arrangement, which can be studied in two- or three-dimensional environments, without giving advantage to any. We modified a tool, called *MAZE*, which we used for related experiments to suit the condition of understanding and describing of volumes within a spatial assembly (Schnabel and Kvan, 2001A).

3.1 Experiment

We set up an experiment to investigate basic understandings of design and communication within a conventional representation of 3D space (2D plans) and 3D models (using Desktop VE (DVE), such as a 3D interactive model displayed on a PC-Monitor, and IVE, with an iterative 3D model viewed with a HMD and its tracking devices). We investigated the differences these conditions may have on an abstract building or volume description, represented by a cube of interlocking shapes. These cubes exhibited different volumes, none of which could be inferred from the surface descriptions of resultant shapes.

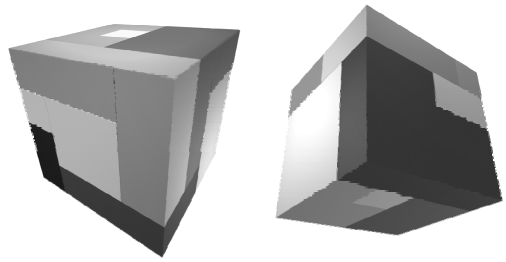


Figure 8: Cube front-top; back-bottom

Twenty-four randomly selected architectural students were asked to explore and study the given 3D cube which was constructed within a 4 * 4 * 4 grid framework (Figure 8). This cube was build of eight coloured and distinguish-different volumes (Figure 9). A time limit of 25 minutes was given to study the cube as well as 20 minutes to rebuild the shapes using 144 wooden cubes, with 18 cubes available for each colour.

In the 2D design environment participants were given four 2D architectural plans, represented the four levels of the cube structure. Participant of the DVE-condition used a web-browser with *Cosmoplayer* plug-in to view a 3D *VRML*-model, while IVE-participants used *MAZE*, which allowed them to navigate and explore the given cube freely and in real time within the IVE.

3.2 Results

Volumes and enclosures are differently perceived and expressed in 3D volumic structures, such as our given 3D cube. It appears that students explored and investigated within the two VEs settings the spatial relationships of the volumes more fluid and had therefore a better understanding of the three-dimensionality. In total contrast of that, students using the 2D medium rebuild the cube as a stack of 2D ‘floors’ not relating to the spatial expression of the eight volumes. Evaluation of the questionnaires, completed by the participant after the experiment, supports these findings. VE therefore offers designers a greater 3D understanding of space and volumes.

However, in the majority of resulting cases participants of the 2D media were able to rebuild the cube nearly without any error (Figure 10.1). Assessment of questionnaires and observations during the experiment proved that the students memorized the individual ‘floor plans’ regardless of their spatial connection in space. This reflects the typical 2D understanding of a 3D building description, in which 3D-space is perceived and

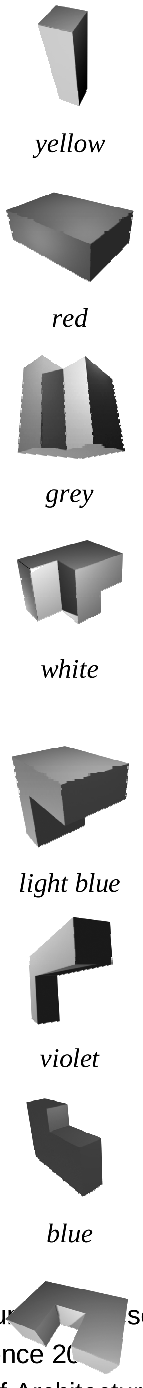
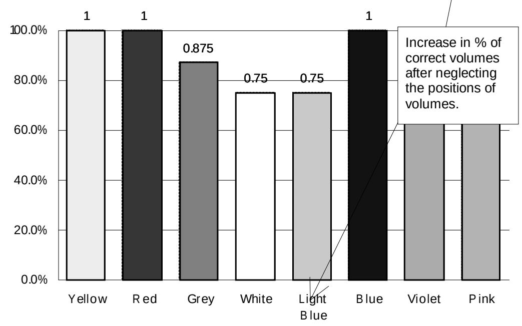


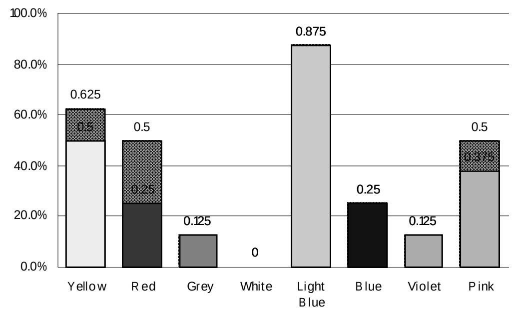
Figure 9: Eight Volumes

Figure 10: Percentage of correct volumes in the different media

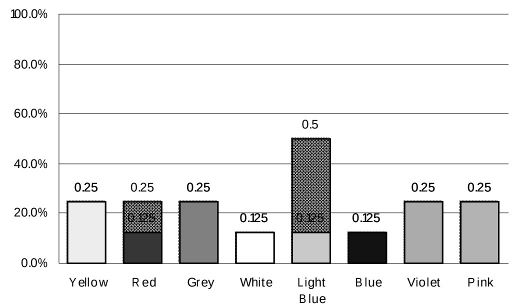
1. Two-dimensional media



2. Desktop VE



3. Immersive VE



translated two-dimensionally. To understand and communicate 3D volumes architects are trained to think and read two-dimensionally. This results in a very particular and 'layered' description of a building. Interestingly the conditions of VE show, despite their relatively low 'success-rate', a constant understanding of 3D volumes and spatial relationships. Distinct shapes of the structure we understood and rebuild. Sometimes participant placed shapes at a wrong location of the cube (such as upside down or back to front), however the volume was recognized correctly and placed in context (Figure 10.2 and 10.3).

While the subjects were able to use the IVE system, the results do show that their performance was substantially worse in IVE than the other systems. When de-briefed, the students noted that the jumpiness of the image and the weight of the headset were significant inhibitors. They reported that settings for ease of use outside the virtual model were not adequate for actions taken when inside the model; for example, when they approached the model, the speed of approach was correct, yet when inside the volumes, the speed was too high. There was no way for the user to modulate the system as they might their own progress through a physical space. Given the significant problems in using a headset IVE, it is striking how poorly the desktop users performed since desktop interaction is now so common and all subjects had several years of experience in manipulating a mouse and keyboard.

4. Discussion

Most importantly, the second set of experiments show that users of an IVE do indeed 'read' the volumes better than when working in 2D representations. The results also show, unfortunately, that IVE tools are still so crude that the characteristics of the systems inhibit their effective use in design tasks.

According to Davidson and Campbell (1996) VR is a constructive tool to support the design and communication process, at least in establishing co-presence for a joint experience in spatial review. Thus far, how does this aid enlarge to a design setting? Kvan et al., (2000) reported of other VDS results, which have revealed a lack of collaboration and communication. However, our experiments showed the opposite (Schnabel and Kvan, 2001B). Chat-protocols show participants mentioning to each other that the team-working experience was satisfying. The travelling around in space, volume and location was enhanced and site-specific problems were not only better recognized, but also different options investigated, which is an improvement over other forms of design sharing. On one side users of IVE can change their viewpoints and escape gravity, but on the other they remain all the time 'inside' their model without having to translate immediately scales or dimensionalities. Designers can therefore work more three-dimensionally since every object within the VE is experienced through movement and interaction. This possibility offers a different 'conversation' with their design that otherwise is not obvious or possible. Spatial issues are addressed in a manner akin to the real world. The tools enhancing the translation of the designers' and users' mental intention, experiences that were encountered perhaps in spite of the technology used and the abstractness of VE.

These works build upon prior experiments in communication between designers in VE compared to their actions in paper environments and how they collaborate with partners to solve 3D tasks. We carried out an architectural virtual design studio that took issues of VE to a more realistic architectural design scenario (Schnabel et all, 2001), then we reduced the question of volumetric understanding to an abstract problem solving task in order to test issues that arose from the VeDS. In both scenarios our findings are similar. We find that it is important for architects to use in the early design stages a tool that reflects the three-dimensionality of their design such as VE. Using a 2D medium to translate spatial ideas apparently reduces the exploration and communication of volume and space. We demonstrated this with our design example of the heliport and the abstract description of the 3D cube. Designing within and understanding a 3D space, IVE offers new opportunities of languages to designers. Consequently, the field is too rich to cover all aspects in these researches.

Our experiment has shown that IVE can support an immediate, direct, scale-less and intuitive control over a 3D design. However, as of today, capabilities of VE software do not match the sophistication of today's CAD software as well as the predominant training of architects to translate and read 2D plans, representing 3D space. Therefore VE can supplement, but not replace, other design media. An immersive and easy-manageable environment is needed before immersive VR can change effectively the design process outside our research conditions. This can then be used broadly in normal architectural and related applications.

However, it is not as simple as just placing a designer in a VE. The technology needs to be investigated and developed further. Postulations about what works and what does not need to be tested. Technology issues such as usability interface and navigation and have to be further developed to reach the same ease to use and familiarity as any 2D media. Problems with the working environment clearly limited what the designers could do. In particular, clumsiness of gesturing and limited field of vision constrained use. Particular problems encountered were the wiring of HMD and tracker entangling arms or legs; interference of and sensitivity of the tracker; lack of precision in gesture recognition and insert-points of elements; polygon size of models; frame rate of display, rendering and calculation time of models; cost of equipment; inability to support multi-user, multi-viewpoints and networking of VEs are all issues that deserve attention.

5. Conclusion

Two sets of related experiments were successfully conducted. In one, pairs of students formed teams and two teams worked across the network to develop sequentially a design in an immersive environment. In the second experiment, students studied and rebuild a 3D cube, either conventionally using 2D plans, or screen based VE or IVE. In these studies, the procedure was observed to identify the achieved spatial-understanding and the degree of communication. Both experiments have confirmed that design within IVEs can lead to meaningful and new architectural results. The direct feedback of cause and effect of VE in the design process and the enhanced teamwork offers architects a new way to explore, design, interact and communicate spatial constructions. The understanding and description of complex volumes is enhanced within an IVE setting.

Since IVEs play increasingly a role in the design and form finding of architectural creation, virtuality becomes, in that sense, reality. Working in VE architects can explore alternative solutions to those achieved in conventional design methods, despite those issues of visual perception, mental images/workload, errors, comprehension of design and its communication, frequency of creation/feedback/modification-loops as well as impact on the design-creation. Our experiments demonstrate that, the problems of VE are not terminal, preventing effective collaboration, nor are they permanent. Because technical solutions are constantly evolving, difficulties resolved and equipment is becoming more sophisticated, affordable and easy to use, IVE give designers a set of tools (such as other technologies, for example rapid prototyping and automated construction methods), with which they can articulate different ideas in a for most users simple manner. VE permits users to create, visualize and communicate ideas with the help of an effective tool.

6. Acknowledgements

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