Design, Communication & Collaboration in Immersive Virtual Environments

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Please use *IE 5.5+* and *Quicktime*.

Abstract

Virtual Environments (VE) are increasingly offered as environments for design. 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 expression. The goal of our study was to identify how designers use and communicate early design ideas by using immersive three-dimensional VEs. We set-up a series of experiments including navigation- and perception-tasks, designing in immersive VE, transcription of design, remote communication between design partners and controlled observations. We explored initial intentions of three-dimensional (3D) immersive design schemes, textual descriptions and collaborations within immersive VE. This article describes the outcome of creation, interpretation and communication of architectural design, by using a 3D maze together with text-based communication in a series of collaborative design experiments. We conducted the first successful attempt of a Joint Design Studio, which uses immersive VE as tool of design and communication between remote partners. We discuss frameworks and factors influencing how architectural students communicate their proposals in an immersive Virtual Environment Design Studio (VeDS), and how this new approach of design studio enables new forms of design expressions.

--> Introduction

1. Introduction

Virtual Environments play an increasing role in (architectural) design (Bertol, 1997). Equipment and software become easy available and especially affordable. However, not sufficient attention has been paid to the results and possibilities of architectural design within Virtual Environment (VE) (Stuart, 1996). Lessons learned from academic contexts have already been employed in commercial settings (ACS, 2001). Virtual Design Studios (VDS) are a widely used method of architectural design teaching. While some have been successful, various issues have been reported, e.g. a lack of communication and collaboration (Kvan, 2000); technology overhead (Kruijff, 1998); and potential contributions to design outcomes (Wojtowicz and Butelski, 1998). In all these design studios, virtuality has been defined as acting while physically distant. Virtual has not yet referred to an immersive VE per se. Instead, VEs were established by the choice of design and communication media: computers, CAAD-programs (2D and 2.5D), VRML, projection screens and automated databases (Donath, et al. 1999). Immersion has not been used for design interaction, although shared immersive virtual spaces have been employed for design reviews (Davidson, et al. 1996). The next logical step to develop the VDS is, therefore, 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. Before engaging in a full VeDS, however, we saw the need to examine the nature of an immersive space in a simple design task.

--> Experiments

2. The Experiments

By using VE to envision ideas the architect is challenged to deal with perception of solid and void, navigation and function, without translations to and from a two-dimensional (2D) media (Campbell, 1996). The goal of our study was to identify how designers use and communicate design ideas by using VEs versa conventional methods of 2D representations such as paper and pen. We focused on the creation and communication of a real three-dimensional (3D) maze as a mean of transportation of ideas and spatial expression. We explored which factors influence designers during the process of design and which role colour plays for the orientation of designers within a 3D environment (Mahnke, 1996). Therefore we assumed that colour is an important factor in orienting designers and participants may design richer structures with the help of colour as a spatial cue. Finally design intentions, their translation/realization, textual descriptions and collaborations within VE or a 2D realm were investigated.

To investigate the context of a VE, we sought tasks that engaged designers at a variety of levels of complexity. Thus, we decided upon two tasks: the design of a 3D maze and the design of a commercial helicopter landing station in an urban setting. These tasks required users to work in three dimensions at all times yet could be abstracted to reduce representational problems. A maze is a simple architectonic task and the results simply measured. The helipad is a more typical architectural task rife with complexities of functional needs (sight lines, access, form, etc.) yet also very much a 3D question. Both tasks including navigation- and perception challenges and were conducted under the same experimental settings and remote communication between design partners and controlled observations permitting transcription of design allowing comparison of the results with earlier experiments (Kvan, 2000). While the maze task was carried out under experimental conditions, the helipad design project was carried out in a design studio (VeDS 2001).

VeDS 2001 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 (VR) 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.

2.1 Getting Lost ***MAZE*** - A 3D maze, which is an abstract architectonical task with a clear goal and
2.2 Ping Pong ***VeDS*** - A real-case scenario of a helicopter landing-ground within an urban setting.

--> Experiment 1 (Maze)

2.1 The Experiment: Getting Lost - MAZE

The design and exploration of mazes appears in various cultures and at various times in history, captivating architects, mathematicians and others (Berer, 1981). On one hand, a maze is a very simple system of forms with clear and simple rules. On the other hand it is a considerable challenge for both designers to create effective mazes and for users to find their way through. For the purposes of an experimental task, we have interpreted maze design to represent a basic architectural problem with which to analyse both process and results. Traditionally mazes are 2D forms, stretching out in length and depth with 'walls' defining or separating the paths. An architect typically deals with complex 3D structures. Therefore a fully 3D maze that works its way through different levels is more appropriate for our research.

We set up two different experiments to investigate basic understandings of design, communication & collaboration within immersive VE:

- Which differences make 2D- versus 3D environments on the results and
- Does colour assist designers in their design process.

We developed a simple tool, which allows user to design a maze within a 3D environment (Schnabel & Kvan 2001A). Eighteen pairs of randomly selected architectural students were asked to design 3D mazes within a 4 * 4 * 4 grid framework (Figure 1) in remote collaborative design sessions. The two members of a pair worked over the network to design a maze. Predefined were entrance and exit on opposite corners of the maze-structure, a time limit of 45 minutes as well as the medium (either 2D design environment or 3D VE). The team-partners could only communicate via a text-window (using *ICQ*-software), so that a description of the design process was recorded, which was analysed later. Previous studies showed that in chat-lines, participants maintain the same amount of high-level design exchanges while the design is not different from the condition of higher bandwidths communications (Kvan, 2000). Additionally both partners had their own independent view of their common maze structure as well as were able to observe the other's design action and movement on screen. The control-group using a 2D design environment used Whiteboard-templates to create their design (Figure 2).

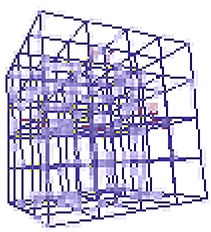


Figure 1: *Screenshot of 3D Maze with a 4 * 4 * 4 grid*

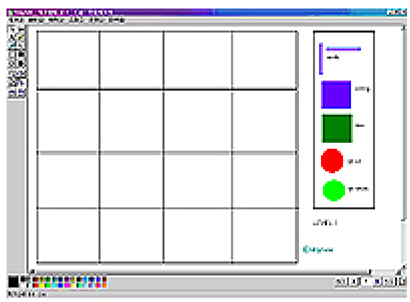


Figure 2: *Screenshot of the 2D design environment with 'Whiteboard' template*

--> Experiment 2 (PingPong)
--> Task 1 (Maze)
--> Result 1 (Maze)

2.2 The Experiment: PingPong or VeDS

This experiment springs from and builds upon virtual studios in which The University of Hong Kong (HKU) and Bauhaus University Weimar (BUW) participated in earlier years (Bradford, et al. 1994; Donath, et al. 1999; Kolarevic, et al. 2000; Kvan, et al. 2000; VDS HKU). Teams on the two sides worked together on the same design task and finished their project within a single day. The design ideas, proposals and modifications were exchanged with the remote partner in short and frequent intervals, reminding us of a ping-pong match. Each side had the authority (not ownership) over parts of the design. Co-ordination became necessary in order not to obstruct the team partner's activity. This set-up simulates a typical scenario where architects and specialists contribute to an overall scheme in sequential and parallel activities that form typical collaborative work (Wojtowicz and Butelski, 1998; Kvan 2000).

The studio focused on the initial design stages of design, comparable to brainstorming and concept finding activities; we did not intend for participants to produce elaborated final designs. As in a moderated discussion session where 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 VE in the course of the alternating sessions described below. To support the design process more fully, text communication was also provided (Wong & Kvan, 1999). We wanted to capture the design intent so we used a modified "think aloud" methodology by establishing a design team of two at each end, one team member wearing the HMD and the other taking notes and chatting with the remote team to convey design intent (see Figure 3). The text records also provided a protocol to be analysed later.

Figure 3: *Teamwork: while one student is designing within VE, the others watch the action and communicate with the remote side*

Figure 4: *Set-up of Equipment: to the left, the HMD with tracking-device; to the right, the PC with communication software and image from the HMD*

In addition to participation in earlier VDS, HKU and BUW have independently conduct research within VE. These experiences proved crucial in the success of VeDS, a process inherently plagued by tremendous technical and operational difficulties. Issues such as collaboration and co-ordination, technical matters of bandwidth, file transfers and communication, have to be tackled as well as tuning of equipment, ensuring equal opportunities for participants and the availability of facilities. Although in the past our goal has been to engage in heterogeneous environments, with each participant using whatever equipment they wish, the problems of VE collaboration precluded such freedoms. In this experiment, both universities employed very similar configurations of immersive (VR) equipment, as shown in Figure 4: a Pentium III computer, connected to a broadband internet connection, monitors, *Kaiser Proview 60 HMD* and a *Polhemus Fastrak* magnetic tracking device and a *Stylus*. The Virtual Reality Architectural Modeller (VRAM) developed by BUW (Regenbrecht, et al. 2000) had been modified and added new input features based on gestures. Comparable to input for PDA-devices, the users now gesture with the stylus and their movements are translated into basic 3D primitives (Figure 5). A second PC was used for the communication-channels *(ICQ)*, Internet *(IE)*, Web-based database and other presentation-software *(AutoDesk 3DStudio VIZ* and *Adobe Photoshop).*

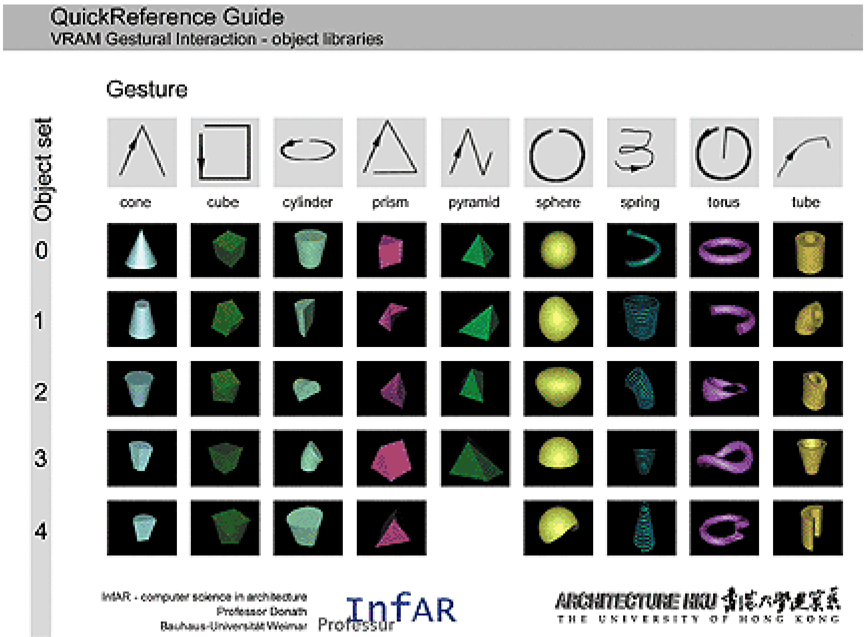


Figure 5: *Gesture Reference Guide*

This VeDS was part of an elective course for students in Hong Kong for the Master of Architecture course. At BUW, the students were in an architectural design studio. The students had acquired both a broad training in *IT* and *CAAD* as well as an advanced background in architectural design. A small exercise was given to the students prior to the VeDS to instruct them in the functions and aspects of immersive VE and VRAM.

Each university had access to only one set of VR equipment; thus, only two teams could work at the same time. The intent was to engage the students in rapid design exploration akin to brainstorming so sessions were completed in one continuous cycle. HMD use is limited in its effectiveness (Wong, 2000) so each phase (called ping or pong) was set to 30 minutes during which they had control of the model. This was followed by file-exchange and fine-tuning/adjustment of equipment (Figure 6).

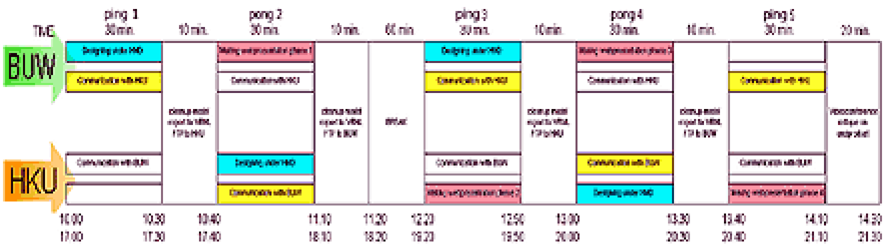
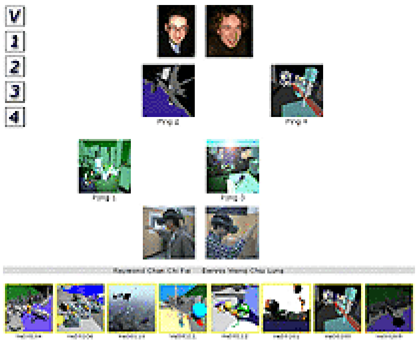


Figure 6: *Time-flowchart*

Within one pair, one team member was designing while the other was taking notes and annotating the design. Then they wrapped up their design, cleaned the model of unwanted elements and placed the model and the text into the database (modelled on Hirschberg, et al. 1999) where they prepared a short presentation explaining design intentions and achievements of that phase (Figure 7). The remote side then took over the model and continued the design work. After alternating four times, the exchange concluded with a final phase where the work was presented within the database. This phasing allowed for potential problems in file transfer or temporary bandwidth constraints.



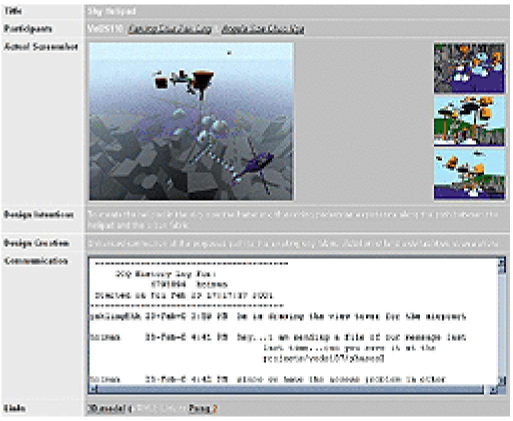


Figure 7: *Screenshots of Database:*
Left: *overview of output by one team*

Right: *presentation of work in one phase with text annotation [http://courses.arch.hku.hk/vds/veds01/db]*

Using this sequence, a complete cycle of VeDS was finished within four hours and could be repeated daily over one week in order to accommodate all teams. With this method 18 groups in total took part in the studio. After the last teams completed their work, a final critique supported by a internetbased video-conference was arranged in which all teams came together presenting their work to each other, instructors and external examiners in order to discuss the different outcomes and the new approach to design.

--> Tasks
--> Task 2 (VeDS)
--> Result 2 (VeDS)

3. The Tasks

The design tasks were specified that presented the students with assignments appropriate in scale, content and effort to the medium available. Factors taken into account included technical constraints (tracker range, room size), the scale of model and points of view (gravity, birds-eye view). Special care was taken neither to favour a condition nor to hinder the designers in creativity and translation of idea and result.

--> The Maze

3.1 The Task: Maze

In the 2D design environment participants could only draw on a paper/pen equivalent medium by using 'Whiteboard'. They were offered a grid template, which represented the four levels of the maze structure (Figure 2). However, students were free to sketch in their own style, even three dimensionally.

We developed a tool, which allows users to fly though a 3D VE and create a maze by placing walls in all directions of a grid framework (Figure 8). This networked application allows interaction, viewing and manipulation of the structure independently of the other participant. The user can move freely in every direction, zoom, place and delete walls as well as see a representation of the team-partner, his/her movements and actions on the screen in real time.

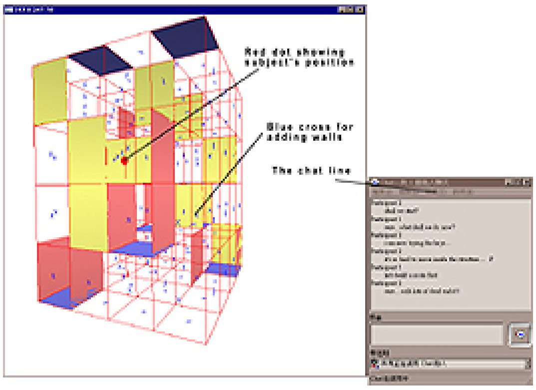


Figure 8: *The 3D design environment: the Maze-program and the chat line*

Colour is a significant factor in an architectural environment that can influence the behaviour of its users (Mahnke, 1996). To investigate whether colour would assist designers in a 3D environment, another two conditions were set up. One set of tests was carried out in polychrome in which the maze and its walls of each dimensional plane had a distinct colour. The other series were to be resolved in monochrome in which the maze, its structure and all elements were in shades of grey only.

--> The VeDS
--> Result 1 (Maze)

3.2 The Task: HeliPad

The task defined was a small landing-ground for helicopters in Central, Hong Kong. One the one hand, the Hong Kong Government is searching for a design of a new Helipad at the location, on the other, the task fits the constrains and opportunities of VE. In this task, the designer can work in a virtual model of Hong Kong from the viewpoint of the pilot or of the passenger waiting to embark. The task was split therefore in two parts, one for each team: the land- or the airside of the helipad. Additionally each part of the task had one static and formal, the other dynamic and path focused, which had to be addressed in the design proposal:

- Landside: Check-in/waiting enclosure for passengers ➞ static
Driveway/parking ➞ dynamic
- Airside: Control tower for Air controllers and tourists ➞ static
Apron/flying ➞ dynamic

Each step during the process was recorded and collected. All participants filled out a questionnaire, in which we enquired about the participant's individual IT- and VE-background and experience of this VeDS. Those and all other collected data were recorded for later analysis and further research.

--> Results
--> Result 2 (VeDS)

4. The Results

Most importantly, we demonstrated that it is possible to successfully design, communicate and collaborate in immersive virtual environments. Although it was possible for the teams to concede to the technical complexity of the system and the difficulty of working together, the teams did engage in collaborative work, building at each step on the work of the efforts of team partners and preceding steps.

Secondly, the resultant designs surprised participants in their ingenuity and presentation, as participants noted in the chat line communications. It appears that an immersive VE permitted students to experience their ideas differently from non-immersive environments. They reported that the interaction of idea and creation was direct, that each stroke had an immediate impact on the design. It seemed for the students that they communicated directly with their model, being part of it and not only the distant designer. They told us this led to new forms and new arrangements.

--> The Maze

4.1 The Result: Maze

Volumes, paths and enclosures are differently perceived and expressed in real 3D mazes. It appears that mazes created in 3D VEs permitted students to express and explore their ideas and intentions less ridged, more fluid and therefore more three-dimensional. In total contrast of that, students using the 2D medium designed mazes, which are stacks of 2D mazes making no extent use of the three- dimensionality. VE therefore offered designers to newly interpret traditional 2D mazes.

Interestingly, colour did not assist designers in a significant level. Moreover, monochrome results were constructed with a higher level of detail by placing more walls and creating more 'tunnels' rather than open spaces (Figure 9).

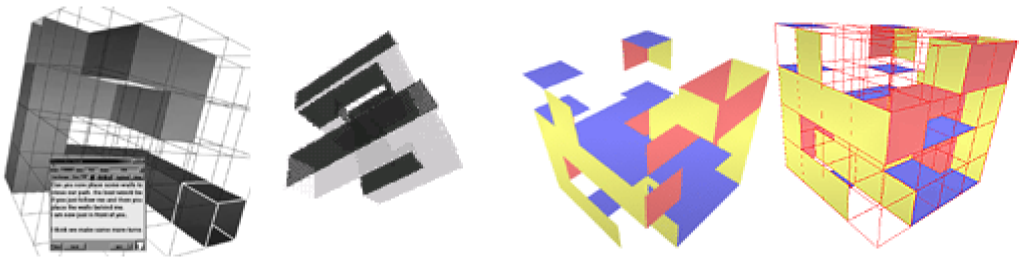


Figure 9: *3D-mazes in its design environment:*
Left: *monochrome solution* **Right:** *polychrome result*

In the majority of resulting cases it was impossible to determine a path of solution. Many mazes were 'open' to different sides and grid-fields have been (intentionally) left blank. To investigate the richness and complexity of the solutions we subdivided the grid-structure into its individual cells. We analysed the numbers and directions in space of each wall at this nucleus (Figure 10). With this method we were able to interpreted the mazes and formulate differences in the design behaviours.

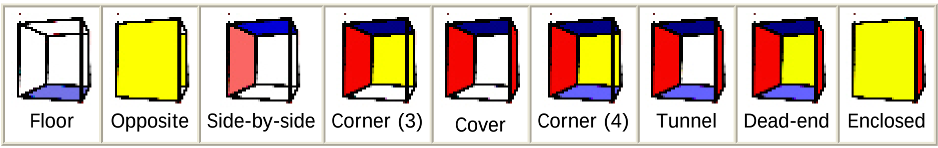


Figure 10: *Cells analysed by its wall count*

We noticed that polychrome- as well as 2D- mazes had a large portion of cells composed of one to two walls (i.e. "floor" and "side-by-side") only, monochrome mazes showed a broader range of usage of cells (Figure 11 & 12), with correlated use of "floor" and "tunnel".

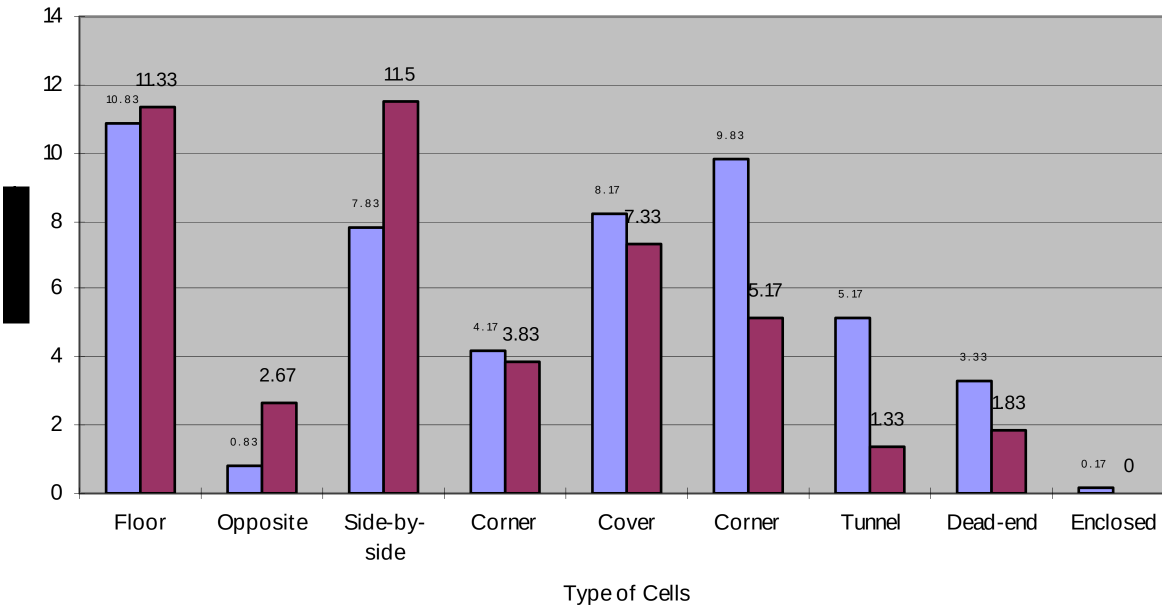


Figure 11: *Comparison of mean number of different types of cells*

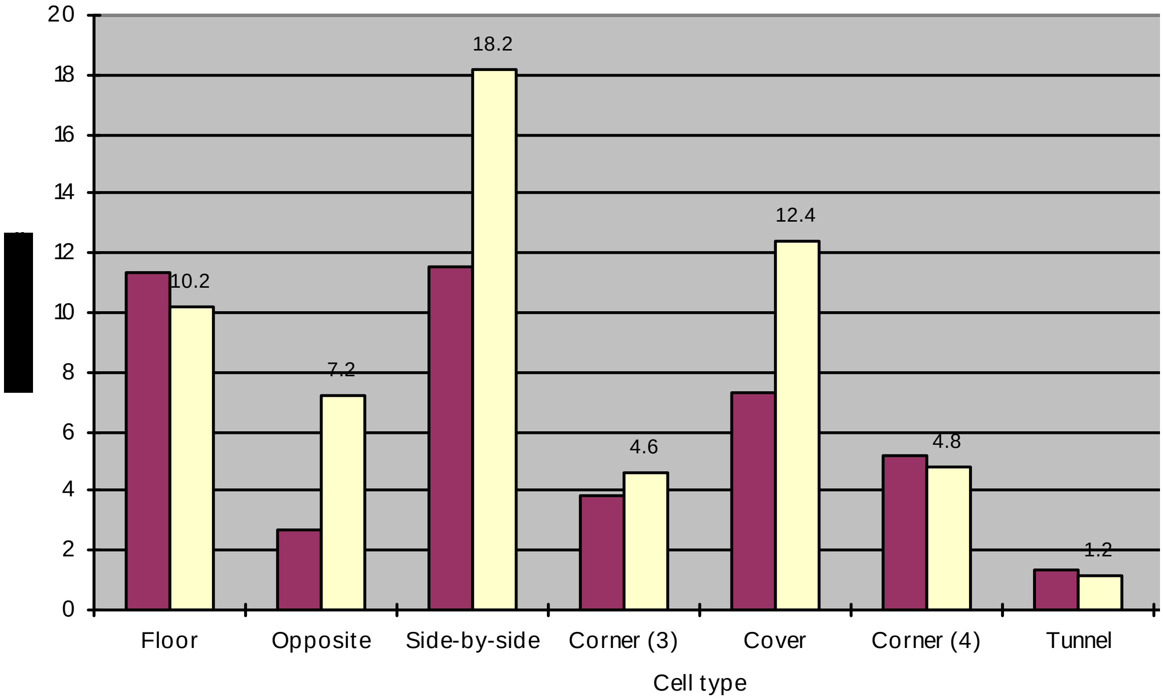


Figure 12: *Mean distribution on the 9 types of cells*

The analysis of the chat communications showed that teams did engage in collaborative work. These data show that students using the 2D medium discussed issues of design significantly more and longer compared to the 3D medium. Surprisingly the teams using the monochrome environment engaged in fewer discussions about navigation, orientation or interface than the polychrome teams. Students designing a monochrome maze also communicated about design issues significantly more often and longer than those designing in polychrome. By comparing the average number of exchanges between poly- and monochrome mazes, the two groups of participants showed a similar trend discussing design issues more frequent than other topics, such as navigation, interface or 'null'-matters (Figure 13). These data raise a number of questions, these will be addressed in Discussion.

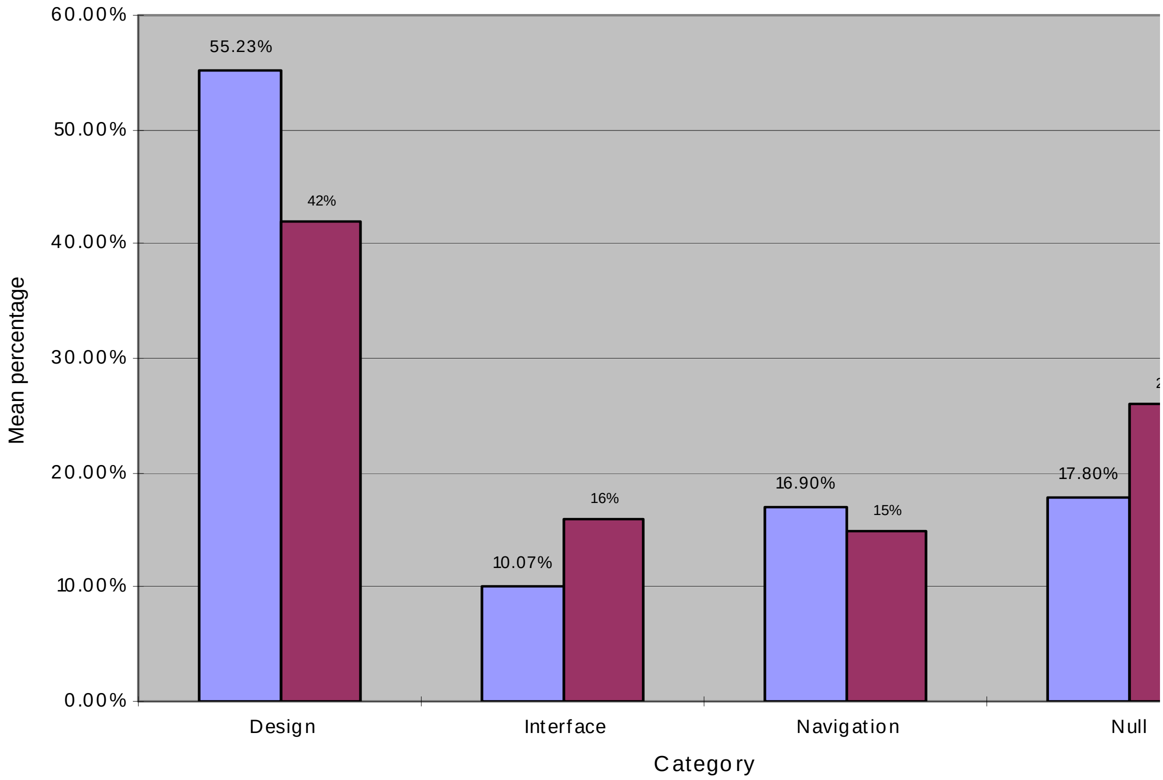


Figure 13. *Comparison of mean percentage of categorized polychrome and monochrome chats*

--> The HeliPad (VeDS)

4.2 The Result: HeliPad

To begin with, the resultant designs surprised participants in their ingenuity and presentation, as participants noted in the chat line communications. It appears that an immersive VE permitted students to experience their ideas differently from non-immersive environments. They reported that the interaction of idea and creation was direct, that each stroke had an immediate impact on the design. It seemed for the students that they communicated directly with their model, being part of it and not only the distant scale-less designer. They told us this led to new forms and new arrangements.

Collaboration was possible. The interaction within the team worked out much better than anticipated. Communication problems of earlier VDS did not occur (Donath, et al. 1999; Kolarevic, et al. 2000). The teams engaged in intense discussions about design, concepts and form. Due to the nature of the task and application the groups had to formulate their actions to the remote partners to be able to develop further their scheme. In addition the participants developed a personal interest to share their experience and creation with their colleagues and other teams. We noticed that participants from BUW tended to deal with conceptual schema while HKU students tended to be factual, specific and describe in tangible terms, possibly reflecting the educational characteristics of the two institutions. It is notable that the VR environment supported these differences and the collaboration was successful with such distinctions.

The intention was to use immersive VE as a tool to create and communicate design as part of a whole design-process. The studios served as base for further exploration and development of the design-task. The results are therefore only slices of more extensive development and not wholly elaborated and finished schemes. The results are initial exploration of the participants' ideas and act as visual communication tool of its meaning.

Initial reviews of the graphic results suggest that the students used the three-dimensional design space actively. Volumes were created to represent design elements at all cases within the 3D design space available. Typically, a design created in a 2D space would have located elements in plan with some raised in section/elevation to create three-dimensional spaces. In this experiment, however, the students started 'drawing' the design elements at all points above the ground plane. Observation during the creation of the design show that participants did not use a 'bottom-to-top' (floor by floor), an 'inside-out' (function defines form) or 'outside-in' (form defines function) approach to their design. Students mostly used an integrated design-method. Being virtually inside the model, they sculpted their proposals, employing the flexibility of viewpoints offered in VE. They explored the spatial impact of their design proposals in relation to existing forms and activities from outside and within the model (Figure 14). Although the input systems were crude and clumsy, users rapidly learned to represent their design intent by using representational volumes: cubes and spheres (Figure 15). These primitives symbolized both positive and negative representations of space. Viewers of the model, however, were able to understand this ambiguity (Figure 16). In some cases, because of lack of experience or the complexity of the VE, errors or coincidences were transformed into meaningful architecture (Figure 17), a design behaviour observed in more traditional 2D design environments as well (Schön and Wiggins, 1992). Other instances demonstrate that students were inspired by their three-dimensional model and translated their design back to a (mental) two-dimensional image (Figure 18). Differences in design- and operation-skills as well as architectural language can also be detected (Figure 19).

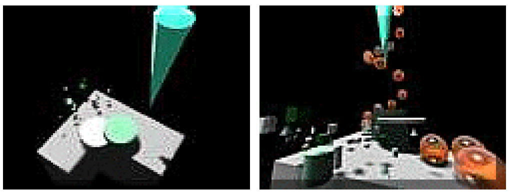


Figure 14:
Users are involved (in terms of scale, viewpoint and navigation): design that uses the flexibility of VE, offers to explore structure and its spatial impacts on the creations (Playground, VeDS104)

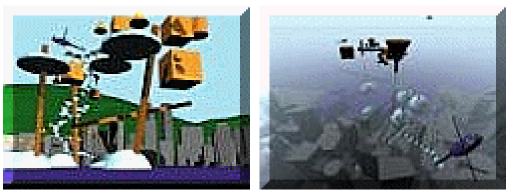


Figure 15:
Primitives representing functions or forms, independently of their actual 3D shape (HeliPad, VeDS110, Phase 3 - 4)

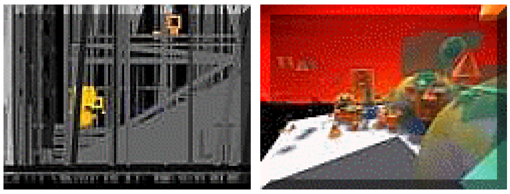


Figure 16: *Primitives can symbolize both positive and negative representations of design-elements, remaining interpretable by viewers of the model (HeliPad, VeDS108, Phase 3; Playground, VeDS112)*

Figure 17: *Lack of experiences or complexity of the VE, created errors, which are transformed into 'meaningful' architecture (Playground, VeDS103)*

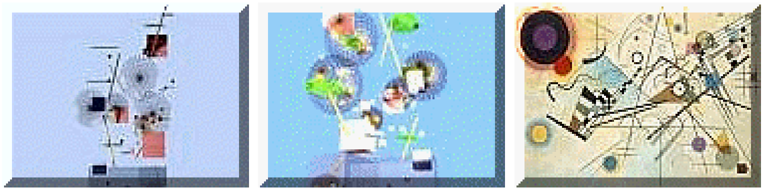


Figure 18: *Plan and perspective of design with an painting by Kandinsky as mental inspiration - image added later by student (Playground, VeDS106).*

Figure 19: *Differences in design- and operation-skills as well as architectural language can also be observed (HeliPad, VeD106, Phase 2-4)*

We expected a high number of navigation-/orientation discussions as well as explanations of meaning of elements placed in the scheme. Surprisingly, the chat texts show only a few lines of such conversations (Figure 20). This suggests that participants could not only orientate themselves easily within the VE but also were able to abstract and extract the design-intent of the remote partner without much difficulty.

pakling@hk 23/2/2001 3:21 PM we are creating the steps leading to the sky helipads....(using cubes)
pakling@hk 23/2/2001 3:26 PM maybe think cylinders would be appropriate.....
hoiman 23/2/2001 3:26 PM good! hum u can see...there is a cylinder beside the pland platform... we think they are the back office for the helipad..
pakling@hk 23/2/2001 3:27 PM we may create cubes and spheres.....

Figure 20: *Excerpt from Chat line of Phase 2: VeDS107 (hoiman) and VeDS110 (pakling)*

While the text records do not, identify how or why the students were using the 3D space in these ways, we do find records of intense discussion about design, functions and concepts (Figure 21). Students engaged in design discussion and development of the scheme by referring to the images they saw in the model provided by their distant collaborators.

hoiman 23/2/2001 15:34 may be you can make the modification for us... but we think the helipad should a little bit higher than the buildings surround...
pakling@hk 23/2/2001 15:35 we would modify our objects... so as to connect to your helipads
hoiman 23/2/2001 15:35 hey....i have an idea...can we have some connection to the surrounding buildings... since it is much more meaningful that the helipads can serve the other commercial buildings.
pakling@hk

23/2/2001 15:36 ok...we would see if we can achieve that...
hoiman 23/2/2001 15:39 i think a few connections to the adjacent buildings such as the Central Plaza and the Attic building and the Academy for Performing Arts building would be nice..

Figure 21: *Excerpt from Chat line of Phase 3: VeDS107 (hoiman) and VeDS110 (pakling)*

The complete documentation of this VeDS can be viewed online at http://courses.arch.hku.hk/vds/veds01/db .

--> Discussion

5. Discussion

We developed our experiment based on reported results from 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 some experiments on abstract problem solving tasks, then transferred our experience to an architectural virtual design studio that took the issues to a more realistic architectural design scenario (Schnabel et all, 2001). In both exercises our findings are similar. In the early design stages, we find that it is important for architects to use 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, at least in the design example of the heliport we present here. Designing within an immersive VE offers new opportunities of expression to designers. Thus, the field is rich for exploration..

It has been found that VR is a constructive tool to support the design and communication process (Davidson and Campbell, 1996), at least in establishing co-presence for a shared experience in spatial review. Yet how does this support extend to a design setting? Other VDS results have exhibited a lack of collaboration and communication (Kvan et al., 2000), however, our experiments showed the opposite (Schnabel and Kvan, 2001B). Chat-protocols show participants remarking to each other that the collaborative experience was satisfying. The exploration of space, volume and location was enhanced and site-specific problems were not only better recognized, but also possibilities investigated, an improvement over other forms of design sharing (Campbell and Wells, 1994). Users of immersive VE can change their viewpoints and escape gravity, but remaining all the time 'inside' the model without having to translate scales or dimensionalities. Digital three-dimensional models are generated with immediacy similar to physical models, constructed to improve the perception of designs developed by drawings. Thus VE provides through its involvement an immediate feedback to its users, which is not possible within CAD or traditional design media. 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 process of design becomes more immediate in some aspects, with 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.

Our experiment has shown that immersive VE can support an instantaneous, direct, scale-less and intuitive control over a (three-dimensional) design. However, as of today, VRAM capabilities do not match the sophistication of today's CAD software; it 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 appears to be not as simple as just placing a designer in a VE. The technology needs to be investigated further. Assumptions about what works and what does not work need to be challenged. For example, we did find that the addition of colour as a visual enhancements distracted the designers while navigating in an immersive environment. 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. The HMD hindered users; particular problems encountered were the wiring 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.

--> Conclusion

6. Conclusion

Two sets of experiments were conducted. In one, students worked in pairs to design a maze over the network, one pair working immersively while the other worked on a shared screen-based drawing system. In the second experiment, pairs of students formed teams and two teams worked across the network to develop sequentially a design in an immersive environment. In both experiments, the processes were observed to identify the degree of collaboration achieved. These studies have demonstrated that design communication and collaboration in immersive virtual environments can lead to meaningful and new results. The interactivity of VE in the design process, the direct feedback of cause and effect and the enhanced collaboration offers architects a new way to explore, design and communicate spatial constructions. While problems remain in the technologies, the rapid asynchronous manner successfully enabled students across the world to participate with immediacy in joint development of a design solution.

Immersive VEs play increasingly a role in the design and form finding of architectural creation. Virtuality becomes, in that sense, reality. Possibilities that have only been imagination of creators can now be visualized and communicated to both professionals and laymen. Our experiments demonstrate that working in VE, fraught with 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, can allow users to explore alternative solutions to those arrived at in conventional design methods. The issues of VE are not terminal, preventing effective collaboration, nor are they permanent. Technical solutions are constantly evolving, problems resolved and equipment is becoming more sophisticated, affordable and easy to use. Immersive VE combined with other technologies, such as rapid prototyping and automated construction methods, give designers a set of tools, with which they can express different ideas in a for most users straightforward manner. VE is becoming an effective tool that allows users to create, visualize and communicate ideas.

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