CREATION AND TRANSLATION

Virtual 3D architectural environments

MARC AUREL SCHNABEL
Department of Architecture; The University of Hong Kong
Hong Kong; P.R. China
marcaurel@hku.hk

Abstract. In this paper, we describe the research we undertake to investigate the perception and comprehension of spatial volumes within immersive, non-immersive virtual environments and physical models and their translation to a tangible representation. We set up two related design experiments to investigate the outcome of creation, interpretation and communication of architectural design. One, being the analysis of a cubic structure, based on three-dimensional (3D) interlocking volumes and spaces; and the other, being the design of a 3D-maze together with text-based communication. Collaboratively participants create, assess and analyse spatial relationships of volumes and spaces of a 3D maze structure or construct models of these spaces. The objective of our study is to identify how designers perceive space in Virtual Environments (VE) and communicate design ideas by using VE versa conventional methods of two-dimensional depictions such as paper and pen or 3D representations such as physical models. We investigate issues of quality, accuracy, understanding, communicating and rebuilding of designed or experienced architectural compositions.

1. Introduction

In most cases the overall dimension of an architect's final 'product' as well as the involvement of material and manpower makes it impossible for designers to communicate and express their intensions in real scale and direct translation. In recent years technology has offered architects a new tool: Virtual Environments (VE). Architects use VE increasingly as a device of communication and presentation of design intensions (Bertol, 1997). VE-equipment and presentations are not only used in academic or professional settings but also for gaming and other consumer activities (Leach, 2002). VE are employed successfully to study, communicate and present architectural design. According to J. Maze (2002) VE it is seldom used for creation, development, form-finding and collaboration of architectural design. Immersive-VE (IVE), which enable users active and real-time interactions with design have not yet been used widely for in the process of design. IVE offer new opportunities and solutions to architectural design problems (Schnabel and Kvan, 2001) through their involvement in a three-dimensional (3D) medium.

The design and exploration of mazes is a fascinating topic throughout history of architectural design (Berer, 1981). On one hand a maze is a very basic task with clear and simple rules. On the other hand it is a considerable high challenge for both designers and users. A maze represents a fundamental architectural problem, which allows an objective analysis of process and results. Traditionally however, mazes are two-dimensional (2D) stretching out in length and depth with 'walls' defining or separating the paths. Architects always deal with complex 3D structures. Therefore a real 3D maze, which also expands into different levels, is more appropriate for our research.

The results of an IVE Design Studio suggested further research is needed to clarify just how well 3D forms are understood within IVE (Schnabel and Kvan, 2002). Taking the issues therein stated into account, we set up two sets of experiments to explore some basic questions of how designers utilize IVE.

Firstly, we conducted a series of experiments to look only into the issue of understanding of 3D elements in space. They engaged architectural students in describing forms they examined in IVE, thus investigated the relationship of 3D space perceived within VE as compared to descriptions made in the physical realm.

Secondly, we were to identify how designers use and communicate design ideas by using VE versa conventional methods of 2D representations such as paper and pen. We focused on the creation and communication of a real 3D maze as a mean of transportation of ideas and spatial expression. We also 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). Assuming colour is an important factor we anticipated that designers might create richer structures with the help of colour as a spatial cue.

The paper describes the two experiments and its developed tool. We demonstrate despite the fact that 2D representations of 3D space are the pre-dominant medium to understand and communicate spatial arrangements, and that designer's understanding of complex volumes is enhanced within a VE setting.

2. The Experiments

For the purposes of an experimental task, we interpreted an abstract architectural arrangement that can be studied in 2D or 3D environments. We developed a tool, which allows users to 'fly' though 3D VE and create a maze by placing walls in all directions of a 4 * 4 * 4 grid framework. Our networked application allows interaction, viewing and manipulation of the structure independently of the other participant. The user can in real time move freely in every direction, zoom, place and delete walls as well as see a representation of a team-partner, his movements and actions on the screen. This reflects architectural design processes in which volumes and space are examined that determine the overall layout of its design. In our experiments the maze also enables students to experience and study enclosed volumes within a spatial assembly. A given cubic structure simulates a simplified architectural spatial configuration that can be analysed, interpreted and transcribed by using immersive and non-immersive media. Special care was taken neither to favour a condition nor to hinder the designers in creativity and translation of idea and result.

2.1. THE CUBE

The experiment was designed to investigate and compare students' understanding of volume and space as described in three different realms of representations. The first one being a conventional depiction of 3D space in conventional 2D architectonical floor-plans; the second and third using digital 3D models, using either Desktop-VE (DVE), interactive *(VRML)* models displayed on a PC-Monitor, or IVE using an virtual reality models viewed with a head mounted display *(HMD)* and its tracking devices. We studied the differences these conditions may have on an abstract building- or volume-description, represented by a cube of interlocking shapes. This cube exhibited different volumes, none of which could be inferred from the surface descriptions of resultant shapes. We assembled the shapes following a principle of architectural hierarchy and structure (Figure 1).

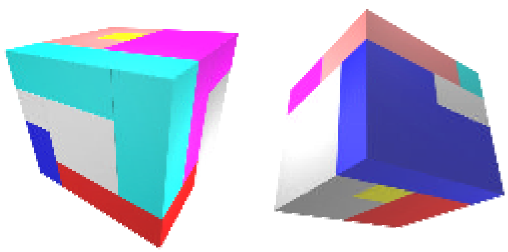


Figure 1: Cube front-top; back-bottom

Twenty-four architectural students were asked to explore and study the given cube. This cube was constructed of eight coloured and distinguishable different volumes. The colours were used to facilitate a better navigation and understanding of the shapes, while eight pieces of shapes allowed us to generate a variety of distinct volumes without being fragmented or understandable from reading the surface descriptions only (Figure 2).

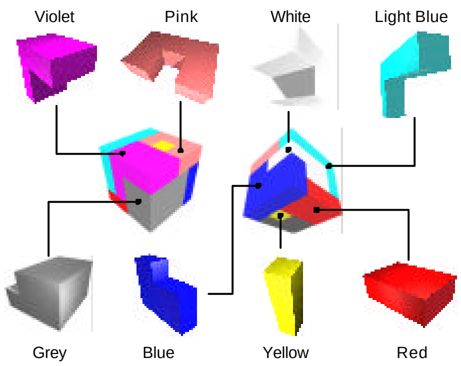


Figure 2: The 8 volumes of the cubic structure

Students were randomly assigned to one of the three representations of the cube (plans, DVE, IVE), and asked to inspect and then reconstruct the structure using wooden blocks. A time limit of 25 minutes was given to study the cube as well as 20 minutes to rebuild the shapes. Since the structure is based on a grid of four units in each direction, all shapes can easily be assembled with cubes of one (cubic-) unit. For all three conditions the students were given a set of 168 wooden cubes, with 21 cubes available for each colour that exceeded the amount needed for each shape (Figure 3).

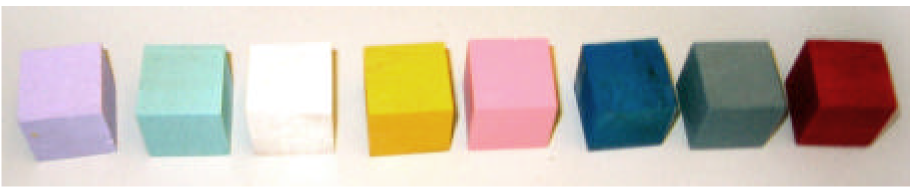


Figure 3: Wooden blocks in eight colours

Finally they participants were asked to complete a questionnaire, enquiring about their experience with the used medium and its representation, the assembly and the understanding of the spatial structure of the cube as a whole as well as its individual shapes.

In the 2D design environment participants were given five 2D floor plans, represented the four levels and top view of the cube (Figure 4).

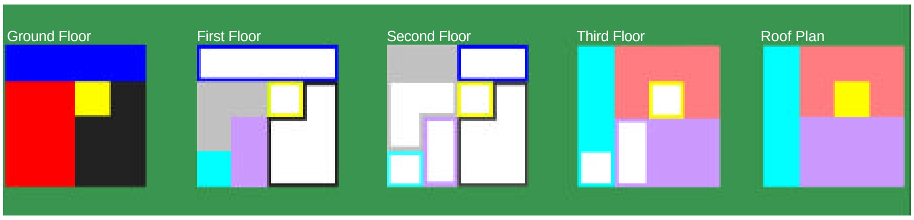


Figure 4: 2D plans for the 2D condition

The plans are all printed on one sheet of paper, using architectural depiction of solids, voids and walls. To achieve a closer similarity to standard architectural plans and use of viewing, we chose paper instead of a screen representation. The plans were in a reduced scale in comparison to the wooden cubes. Similar to the 3D representations participants had to scale the studied plans and shapes to the wooden model. The students of the DVE-condition used a standard web-browser with a VRML plug-in *(Cosmo Player, 2000)* to view interactively the 3D cube-model. That allowed them to walk and fly through the cube to their own liking. Finally IVE-participants used an application, which we developed, called *MAZE (2000)*. It allowed them to navigate and explore the given cube freely and in real time within IVE using standard IVE equipment.

2.2. THE MAZE

We examined the outcomes of two major conditions:
- Which differences make 2D- versus 3D environments on the results and
- Does colour assist designers in their design process?

2.2.1. 2D versus 3D

Eighteen pairs of randomly selected architectural students were asked to design 3D mazes within the grid framework of the maze in remote collaborative design sessions (Figure 5).

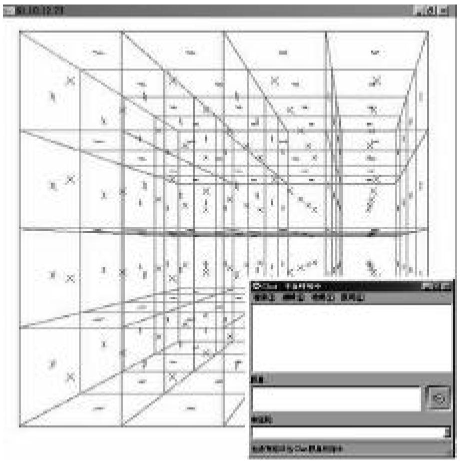


Figure 5: 2D plans for the 2D condition

Predefined were entrance and exit on opposite corners of the maze-structure a time limit of thirteen minutes as well as the medium. The team-partners could only communicate via a text-window, 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.

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 6). However, students were free to sketch in their own style, even three dimensionally.

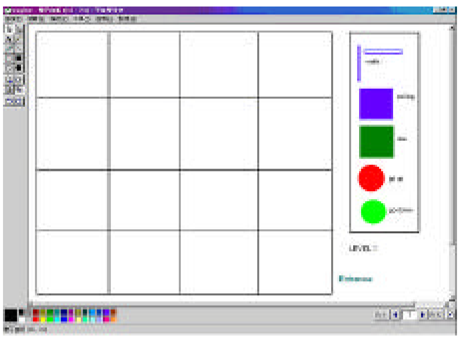


Figure 6: 2D plans for the 2D condition

2.2.2. Colour

Since colour is a significant factor in an architectural environment that can influence the behaviour of its users, we investigated whether colour would assist designers in a 3D environment. For this purpose we set up two conditions for the above described experiment. One being experiments in a polychrome environment, in which the maze and its walls of each dimensional plane had a distinct colour, the other being the same series of test in monochrome display, in which the maze, its structure and all elements were in shades of grey only.

3. The Results

Most importantly, we demonstrated that it is possible to successfully understand, design and collaborate in IVE; although some participants compromised to the technical complexity of the system.

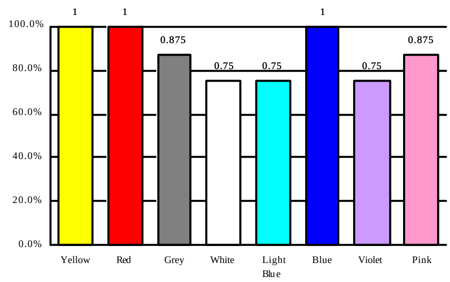
Secondly, it appears that IVE permitted students to examine complex volumes or experience their design differently from non-immersive environments. They reported that the interaction of understanding or idea and creation was direct. It seemed for the students that they communicated directly with their model, being part of it and not only the distant observer or designer.

3.1. THE CUBE

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 VE 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.

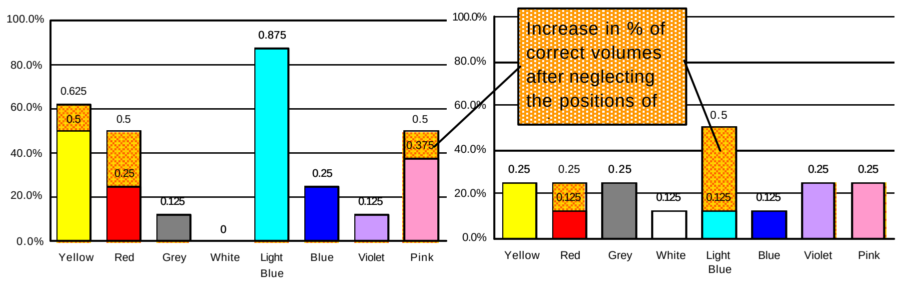
However, in the majority of resulting cases participants of the 2D media were able to rebuild the cube nearly without any error (Table 1).

TABLE 1: Percentage of correct volumes in the different media: 2D media



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 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).

TABLE 2.1: Percentage of correct volumes Desktop VE (left) and Immersive VE (right)



While the subjects were able to use the IVE system, the results do show that their performance was substantially worse than the other media. In the questionnaire completed after the experiment, the students noted that the problems with the technology and equipment were the significant inhibitors in the IVE-medium. They reported that settings for ease of use outside the virtual model were not adequate for actions taken when inside the model.

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.

3.2. THE MAZE

In the majority of resulting cases it was impossible to determine a path of solution. Many mazes were 'open' to different sides and too many grid-fields have been left blank. This made it difficult, to trace an explicit path with turns, alternative routes or dead-ends. 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 7).

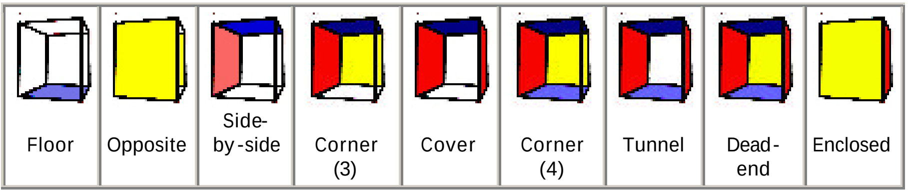


Figure 7: Cells analysed by its wall count

With this method we were able to interpreted the mazes and formulate differences in the design behaviours.

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 (Table 3 & 4), with correlated use of "floor" and "tunnel".

TABLE 3: Comparison of mean number of different types of cells

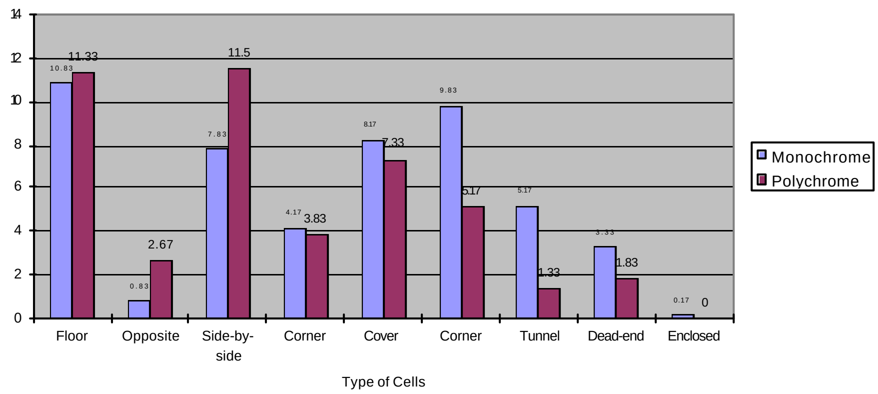
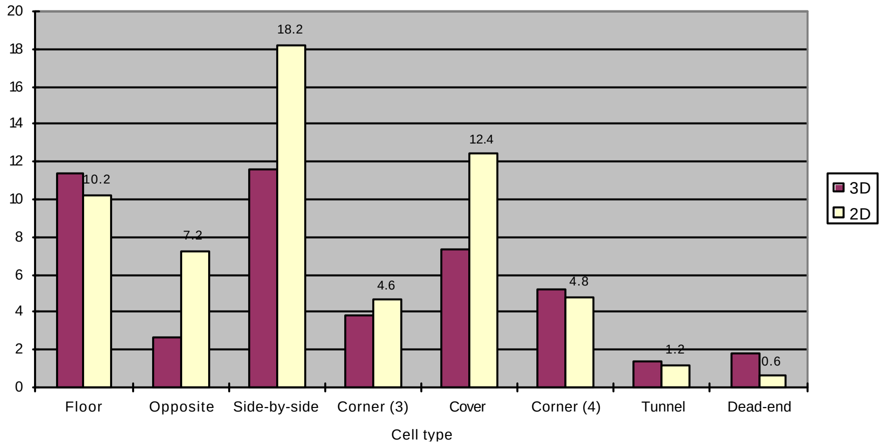
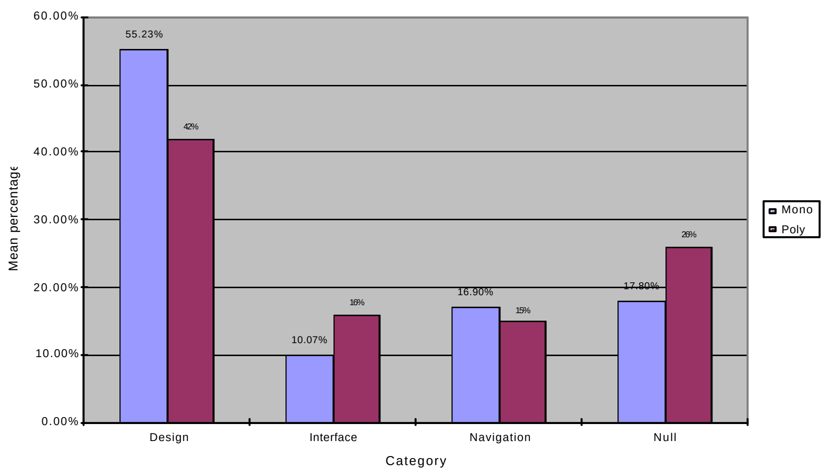


TABLE 4: Mean distribution on the 9 types of cells



The analysis of the chat communications showed that teams engaged in collaborative work. It shows that students using the 2D medium discussed issues of design significantly more and longer compared to the 3D medium. Surprisingly the monochrome-teams engaged in fewer discussions about navigation, orientation or interface than the polychrome. Students designing a monochrome maze also communicated about design issues significantly more often and longer than those designing in polychrome. Comparing the average number of exchanges between poly- and monochrome mazes, the two groups showed a similar trend discussing design issues more frequent than other topics, such as navigation, interface or 'null'-matters (Table 5).

TABLE 5: Comparison of mean percentage of categorized poly - and monochrome chats



4. Discussion

Most importantly, the two sets of experiments show that users of IVE do indeed 'read' 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.

The students who worked in the 2D conditions did succeed mostly. Assessments of questionnaires and observations of working pattern have proven that they engaged in replication of 'floor' plans one at a time, stacked one above the other. Thus, they gained no spatial understanding of the cube or maze. To understand and communicate 3D space architects are trained to think and read two-dimensionally. The VE conditions were less 'complete', but these results showed that users of VE do indeed 'read' the volumes better than when working in 2D representations. The students had a constant understanding of the different 3D volumes or understanding of their design and its spatial relationships. Distinct shapes of the structure we understood and rebuild or clear design strategies applied that made use of the three-dimensionality of the grid-structure of the maze. The results also showed, unfortunately, that IVE tools are still so crude that the characteristics of the systems restrain their effective use in design tasks.

Another point is the enhanced exploration of space, volume and location. On one side users of VE can change their viewpoints and escape gravity, but on the other they remain all the time 'inside' the models. Digital 3D models are generated with immediacy similar to physical models, constructed to improve the perception of designs developed by drawings. Thus VE provide through its involvement an immediate feedback to its users, which is not possible within CAD or traditional design media. Designers experience every object within VE through movement and interaction. This possibility offers a different 'conversation' with the 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.

According to Davidson and Campbell (1996) virtual reality is a constructive tool to support the design and communication process, at least in establishing co-presence for a joint experience in spatial review. Chat-protocols show participants mentioning to each other that the team-working experience was satisfying.

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). In this scenario 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 experiments of the abstract description of the 3D cube as well as the design of a maze. However, the field is too rich to cover all aspects in these researches.

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.

5. Conclusion

Two sets of related experiments were successfully conducted. In one, students studied and rebuild a 3D cube, either conventionally using 2D plans, or screen based VE or IVE. In the second experiment, pairs of students formed teams and worked across the network to develop sequentially a design in VE. 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 VE enhance the understanding of spatial issues and can lead to meaningful and new architectural results. These studies have demonstrated despite the fact that 2D representation of 3D space is the pre-dominant medium to understand and communicate spatial arrangements, that designers' understanding of complex volumes is enhanced within VE settings.

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 IVE 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 medium or technology related difficulties. 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, with which they can articulate different ideas in a for most users simple manner.

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References

Berer, M.: 1981, *Mazes: a problem-solving reader*, London: Heinemann.

Bertol, D.: 1997, *Designing digital space: an architect's guide to virtual reality,* John Wiley & Sons Ltd., New York

Cosmo Player: 2000, VRML-Plug-in for web browsers, Computer Associates International, Inc. Islandia, NY, http://ca.com/cosmo/ - last accessed February 2003

Davidson, J. N. and Campbell, D. A.: 1996, Collaborative Design in Virtual Space - GreenSpace II: A Shared Environment for Architectural Design Review, *Design Computation: Collaboration, Reasoning, Pedagogy,* ACADIA Conference Proceedings, Tucson, USA, 31 October –2 November 1996, pp. 165-179

Kvan, T.: 2000, Collaborative design: what is it? In *Automation in Construction* vol. 9(4), New York: Elsevier, pp. 409-415

Leach, N.: 2002, *Designing for a Digital World (Architectural Design).* New York: John Wiley & Sons Ltd.

Mahnke, F. H.: 1996, *Color, environment, and human response: an interdisciplinary understanding of color and its use as a beneficial element in the design of the architectural environment,* Van Nostrand Reinhold, New York

Maze, J.: 2002, Virtual Tactility: Working to Overcome Perceptual and Conceptual Barriers in the Digital Design Studio, *Thresholds - Design, Research, Education and Practice, in the Space Between the Physical and the Virtual*, 2002 ACADIA Conference Proceedings, Pomona, California, 24-27 October 2002, pp. 325-331

MAZE: 2000, Design, programming, development and manufacturing of software for a 3D-maze; interactive, immersive tool for VE, M. A. Schnabel (ed), Hong Kong, Weimar; http://arch.hku.hk/~marcaurel/phd/mazespec.html - last accessed February 2003

Schnabel, M. A. and Kvan, T.: 2001, Implementing The First Virtual Environment Design Studio. In *Architectural Education for the Asian Century, Proceedings of the 1st ACAE Conference on Architectural Education,* M. Tan (ed), Singapore: Centre for Advanced Studies in Architecture, National University of Singapore, pp.157-166.

Schnabel, M. A. and Kvan T.: 2002, Interaction on a virtual building description; *Distributing Knowledge in Building;* CIB W78 Conference Proceedings 2002, K. Agger, P. Christiansson & R Howard (eds), Aarhus, Denmark, 12-14 June 2002, Vol 2; pp91-98

Schnabel, M. A. and Kvan, T., Kruijff, E. and Donath, D.: 2001, The First Virtual Environment Design Studio; H. Penttilä (ed), *Architectural Information Management,* 19th eCAADe Conference Proceedings, Helsinki, FIN, 29-31 August 2001, pp. 394-400