VRAD (Virtual Reality Aided Design) in the Early Phases of the Architectural Design Process

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With this paper we are introducing a system which supports the early phases of the architectural design process. The system consists of two main components: the software solution 'voxDesign" and the physical environment "platform". Our aim are: to formulate, develop, and evaluate an architectural design system through the use of VR (virtual reality)-space. The exploration and development of design intensions is supplemented by a new method of three dimensional sketching.

Keywords: virtual reality, architectural design, human computer interfaces, design techniques

1 Introduction

Currently available Computer Aided Design Systems are conceived with the purpose of generating a two- dimensional drawing and, eventually, to attach to it information and calculation sheets. The nature of the I/O of such systems, i.e. of the interaction techniques and of the two-dimensional output, both in the form of drawings and of presentation tools, is therefore two-dimensional, although the data to which it refers is often three-dimensional (3D). With the newly available Virtual Reality (VR) technology, it is nowadays possible to build a design system that allows full three-dimensionality in all stages of the design process. This paper describes the conception of a new modeling system, based on VR techniques, which can be used during the early phases of the architectural design process. Such early phases of the design process are characterized by the shaping, in German die Gestaltung", of the three-dimensional space into architectural forms. The system allows the user, in this case the architect, to experiment new 3D-interaction and sketching techniques while being immersed in a "virtual" design space.

2 VR Basics and Exploratory Systems

Virtual reality can be defined as the component of communication which takes place in a computer generated synthetic space and that embeds humans (actors) as an integral part of the system. The tangible components of a VR system are the set of the hardware and software providing the actors with a three-dimensional, or even moredimensional, input/output space, in which, at each instant, the actor can interact in real time with other autonomous objects. Under these premises, we define Virtual Reality Aided Design (VRAD) as Computer Aided Design using the methods of virtual reality. VRAD is nothing particularly new, and can be seen as new application of human computer communication in VR spaces.

In general, communication in virtual reality is characterized through individual differences between the actors, through the presence of a private sphere for each actor, through senso-motoric experiences, and through the relationship between information, navigation, orientation, and the different forms of user expression. Thus, a virtual reality aided design system has to be configurable for each actor, has to be separable into a public and a private sphere and able to react in a sophisticated way, as well as to offer access to external information, and, ultimately, to be navigable, i.e. made of recognizeable cues, which are perceived as being non-chaotic and bear correspondencies to the real world.

One main design-goal of an VRAD-system should be the possibility for the actor to experience the space. This is, according to von Foerster [15], not possible without active doing. Thus you have to provide an interaction space in real world which is large enough to move in an appropriate way, i.e. an architectural sized space. Current virtual reality systems do not provide these capabilities. [1..11]

A lot of development and research has been undertaken during the last few years to establish virtual reality techniques in architecture. Most of these systems are simply viewing programs, also known as walkthrough systems. With the exception of viewing controls there is no real interaction. Other (research) systems attempt to provide information displays, computer aided design or planning support in VR. To these belong interesting projects such as the Architectural Space Laboratory ASL in Zurich or the Virtual Design/Given project at the Fraunhofer Society/ Germany, to mention only a few. Essentially, the geometrical methods that can be used to develop a VRAD system fall into three main categories. In a boundary representation model (BRep), an object is described by points, edges and faces, i.e. by its boundaries. In the second category, constructive solid geometry models (CSG) build the objects from readily available simple geometrical objects. Finally, voxel space models partition the 3D space into all-equal elements, each of which represent an atomic element of the space. An object is here represented as a connected set of voxels of the whole space. A BRep model requires a tedious process of construction before an object comes into existence, and therefore distracts from the real task of the first phases of the architectural design, where creativity is most important.

CSG models don't allow sketching with 3D-shapes other than those predefined, and are thus too inflexible for the task of shaping space. Voxel models, instead, look much more promising, since they allow the sufficient fuzziness in the conception phase, but are also accurate enough to provide enough information for rendering on a VR ouput device. A few voxel-based approaches are described in [13] and [14]. The most recent work in voxelbased architectural design has been undertaken by Wang & Kaufman [12]. They use the metaphor of sculpting. A complex 3D-model is derived from a solid material by carving and sawing. This way is promising for the design of highly detailed objects. Through the use of interpolated voxels and textures, Wang & Kaufman attempt to generate realistic looking results. For our purposes we don't need such fine graduation in design. Our approach is from the opposite end - the coarse, simply 'bordered' model, the elementary form. The above approaches aim for 'near-as' photorealistic virtual images. This brings with it the resulting well- known problems associated with rendering time, resolution, texturing, etc. The second major criticism is the limited s ace of the users action/ movement. Most of the todays VR applications; are desktop-based, some allowing the user to interact on a one square-meter on We want to emphasise the space required for Doing. That means that we want to support a 1:1 experience for the user/actor.

3 A New Approach to Shaping

Our aim consists of three components: to formulate, develop, and evaluate an architectural design support system through the use of a VR space. The exploration and development of design intentions is supplemented by a new method of three dimensional sketching.

A universal and definite theory that describes the exact PROCESS of architectural design does not exist. The direction and individual steps of a design are dependent upon the task at hand, the designated site, not to mention the mentality of the architect his or herself.

However, in direct contrast to the process of architectural design, much is known about the TECHNIQUES applied in the design process, in particular with relation to form finding and external expression. The model (working or development model) and the sketch, play the most important role as traditional methods of design exploration. Sketching, in particular, has special importance as a design instrument. The sketch encompasses the entirety of a design, communicating the functionality of a floor plan in addition to its spatial definition. Sketches are the abstracted pictorial intentions of architects. In contrast to the finished architectural design drawing, the sketch contains the thoughts and deliberations of the architect. This, as opposed to the design drawing, is the early phase of the design process. Sketching is at once the direct formulation and the description of new ideas. It represents as much a method of feedback, testing as of documentation. The sketch is also the discovery of the unintentional. It occurs as memo, half-formed idea, thoughts of the moment. The architect Norman Foster describes it as follows: "How *can you design the plan, section and facade of a building, without sketching the three-dimensional aspects in the margins, without feeling it through the pen* [20] Sketching is, therefore, an essential part of the architectural design. The developments of "voxDesign" choose not to exclude the Model or the Sketch. The possibility to directly and spatially (three dimensionally) design space EXTENDS the existing working methods of the architects with a third new design technique. The degree to which it wilt be used and the particular set-up in which it will be applied, is dependent upon the situation and the architect. The defined design environment of the experimental system aims to provide a 1:1 architectural interior space. Through the use a 4m x 4m physically bound movement space, any form-element or spatial situation can be directly described, observed, modified or discarded.

3.1 The project "atelier virtual"

This project was founded by setting up a multidisciplinary project group in Autumn 1994. Four different disciplines are involved in the project: computer science, architecture, product design and psychology. At first it was necessary to bring together the multiple views on virtual reality. The main topics of the discussion were:

- investigations about real and virtual space including the coherencies
- forms of communication and recognition in virtual worlds
- navigation in virtual space(s)
- interaction with virtual objects
- information displaying
- questions about ethics and social responsibility

Although the results of this discussion are not that spectacular this kind of approach was necessary for founding a workable group. The different and individual views and attitudes were expressed via 3D- modelling and -animation tools (non-VR). Some problems are still unresolved: realistic vs. symbolic information displaying, circumstances in which a private sphere is needed, to mention a few. The discussion and the results are documented in [16] and [17]. To establish a more precise imagination of the possibilities and limitations of VR two additional sub-projects were set up: the "platform-project and the "voxDesign'-project.

3.2 VR equipment

Setting up a high-end virtual reality system is very expensive and often exceeds the budgets of architects. We are using a minimal hardware configuration for virtual reality according to the definition of VR given above. The hardware basis is a Silicon Graphics Crimson VGXT with 64 MB of memory. The output is realized with a Virtual Research VR4 head-mounted-display (hmd), a video-multiplexer RGB4 and two Commodore Monitors for presentation purposes. The tracking system consists of a Polhemus controller unit with a long range tranceiver, one hmd-tracker and a 3Ball as a pointing device. The head-mounted-display is operated in NTSC monoscopic color mode. The tracking system works with about 60 Hz for each tracker and is tracking a range of about 5 meters. All the wires are extended and modified for operating in such a large space. We assume that such a configuration will be available for reasonable prices in the next few years. At present it's placed somewhere in the graphics high-end entry/midrange pricing.

3.3 "Platform"

With particular regard to usability tests and other methods of experimental psychology and human- computer-interface-design it is necessary to provide an appropriate physical environment. Todays VR-research testbeds are characterized typically by unstable laboratory conditions. But for hci testing and development you'll need an (real) environment that will free the user/actor from all the technical restrictions (like wires around the legs). Unfortunately some things are not yet removeable and still uncomfortable (especially the head-mounted- display), but we are working on it. To fullfill the desire of a large interacting room the main design goal of the platform-project is to provide an almost unconstraint physical space of about 4x4x2.5 meters. Within this space there are no obstructions to the movement of the actor. The second goal is to integrate all the technical equipment needed for the VR-application (see VR equipment). Thirdly, there must be an appropriate workspace for the operator and respective software developer. The platform should be applicable for both public and research presentations/ tests and for system development too The result of the design is shown in Figure 1.

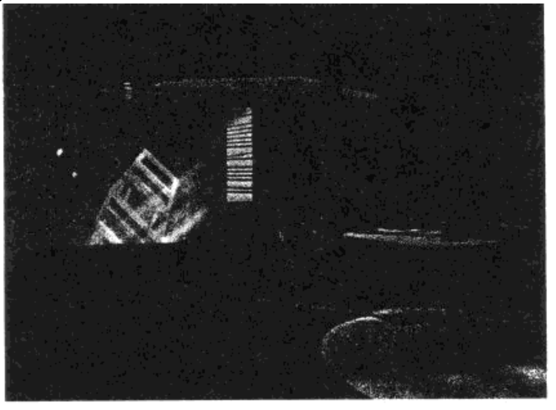

Figure 1

The actor interacts on a circle-shaped floor with about 5 meters in diameter. The hind and the tracker cables are lead through a rod-like construction. Integrated into the whole system is all the equipment needed for demonstrations and development. When used for presentations, the audience can follow the interaction process of the virtual world via two additional monitors and an optional large screen. Some prototypes of the system have been tested and ready to use right now. The final product will be finished in october 1995.

3.4 "voxDesign"

The software solution voxDesign works together with the physical environment 'platform'. Platform" provides the free interaction space in the real world. voxDesign is implemented in C/C++ based on the SGI Graphics Library GL. The main goals of voxDesign are (see also Figure 2):

Figure 2

- Realising a simple (to use and to implement/ modify) virtual reality aided design (VRAD) system for the early phases of the architectural design process.
- Providing an experimental system for studying human - computer interfaces in virtual worlds.

- Using the system for training purposes in architectural and design education.
- Formulation and evaluation of relevant functionality in architectural design.
- Transferring a VR-application from the laboratory to real usage.
- Public presentation of the possibilities and limitations of virtual reality.
- A testbed object/subject for multidisciplinary work in the future.
- Testing of software-techniques for real-time-critic-systems. voxDesign is based on the following premises:

For architects among others, sketching is an elementary form of expression of design-thoughts. VR extends the traditional sketch through the fundamental addition of the third dimension for the design process. Three-dimensional sketching is used as a medium for communication equally with other architects or non- professionals. The 3D-sketch in VR can however, additionally be used for immediate reflection and feedback of the designprocess. The user can operate with the medium of the computer in an intuitive, game-like, experimental way. The early phases of the architectural design process are characterised by fuzzyness, coarse structures and elements, and a trial and error process. Searching for form, shape, ,gestalt is the principal goal of the designer. Small cubes (voxel) are a sufficient minimum element for expression in these early phases. They are the virtual equivalent of the Lego brick in the real world. This is an easily intuitively comprehendable system for the user and avoids the need for extensive trainee-program before using the system.

The development of the software is seperated into two phases: Phase 1, the socalled 'voxDesign0" is already completed and allowed the user to set and erase voxelelements, choosing one color of eight, and to load and save voxel-spaces (see Figure 3).

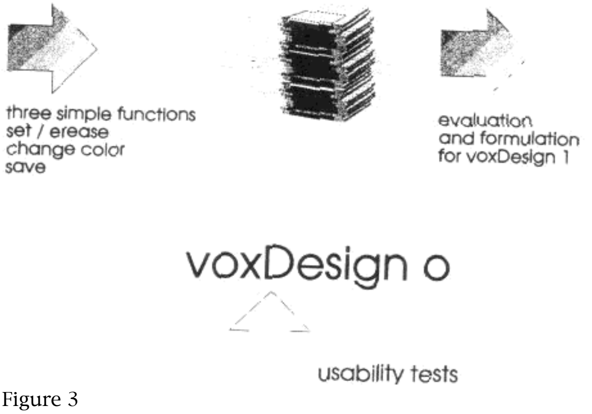

Figure 3

Even with this very simple functionality it was possible to achieve reasonable design-results. "voxDesign0" was necessary to test and evaluate some basic interaction techniques, and to formulate the requirements for voxDesign1 , which forms phase 2 (see Figure 4).

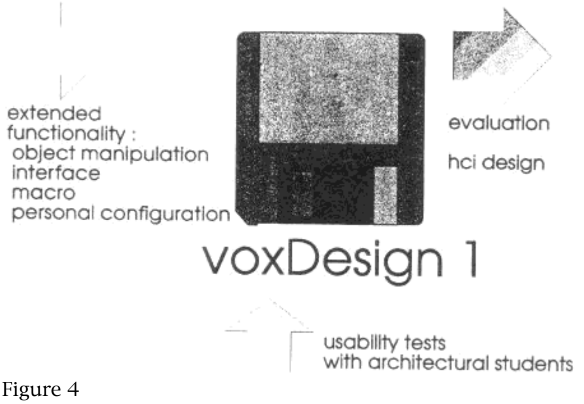

Figure 4

In the following section the functionality of "voxDesign1" will be described. "voxDesign1" allows the user/actor to place voxels (cubes with a volume of 2.5 cubic centimetres) or groups of voxels into the virtual space. The virtual space is the same size as the real interaction space, i.e. about 40 cubic meters. A voxel is represented as an untextured, coloured (true-colour) element. Voxel or groups of voxel can be deleted, moved or copied. To provide an appropriate design-environment it is possible to import threedimensional CAD-models via DXF or pixel-pictures (bitmaps) into the system. In addition to this, the platform provides an analogue audio environment with loudspeakers. The virtual design-space is lit by two ambient lights and two optional positionable spot-lights. The designer can load and save the whole or parts of the virtual model. For presentation purposes a snapshot-function has been implemented. With this function it is possible to print out some views of the model after finishing the design-session. With the platformenvironment it is also possible to record the session on video-tape. Changing the different modes and actions in voxDesign1 is very simple. Either you twist the pointing device or you make a long-click on the button of the pointing device. The preferred method is different for each person and can be selected before starting the session. After twisting/long-clicking a three-dimensional menu appears at the current position in virtual space. The actor chooses the desired option and continues the design process. All user-specific parameters are saved in a configuration-file and can be overwritten with command-line options. An X-Windows based starting interface is currently under development. The sketching process itself is supported by adjustable spray parameters and some simple object-generating tools. This simple functionality allows initial design-thoughts to be expressed in an easy to use way. Resulting examples are shown in the Figures 5-7.

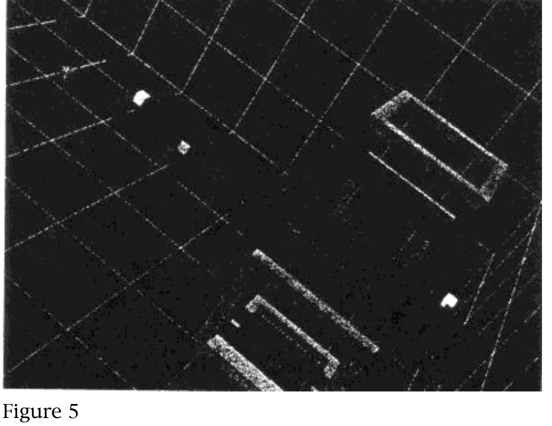

Figure 5

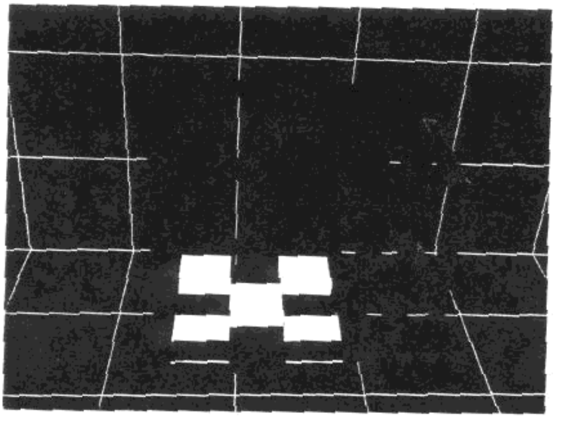

Figure 6

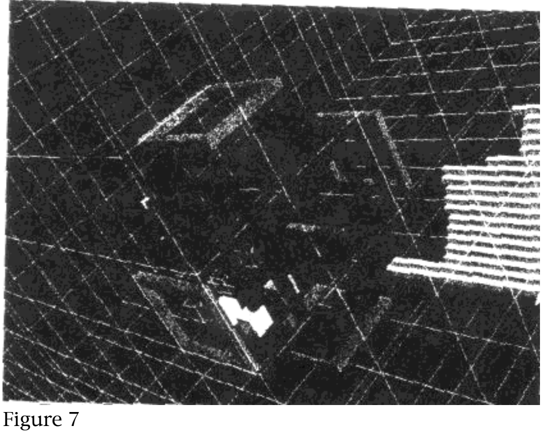

Figure 7

4 Limitations and Future Work

The system in its current manifestation can not satisfy all the needs of the early design phases. A step by step approach is, however, necessary to explore and evaluate the right techniques and to formulate the right questions. Developing and testing human computer interfaces is necessarily an experimental task. Our solution does not support multi-user-design (cscw). It is doubtful whether there is a real need for this in the early formulative design phases. More interesting are problems surrounded by the senso-motoric experience. How can we improve the immediate design-feedback? We are looking for practicable useable techniques. The state of the art in force-, tactile-, and auditory feedback is not yet satisfactory. More promising is perhaps the approach with graspable user interfaces as mentioned in [18]. We'll try to adapt these methods to our VR-system. The currentsize of the interaction space, and therefore the virtual space in a 1:1 experience system, is also too small; the area of design-tasks is reduced to the scale of product and interior design. We are attempting to extend this space using long range tracking methods. Not yet resolved are problems associated with rendering speed and resolution with large numbers of voxels. We are currently working on an algorithmic solution. In addition to this, we hope that the graphics and machine power of the computers of the future will increase. There are many more methodical and technological problems to solve. Our focus is set on defining a wider set of architectural form defining functions. Some theoretical investigations have been undertaken on this subject. We have defined some general principals for object generation and manipulation, extending the voxel idea with elements from brep and csg models. In this case an object is described by points, lines and faces. Moving a point will generate a line, moving a line will generate a face, and so on (see figures 8-11).

Figure 8

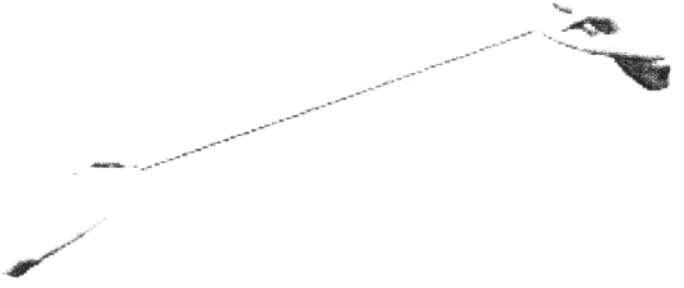

Figure 9

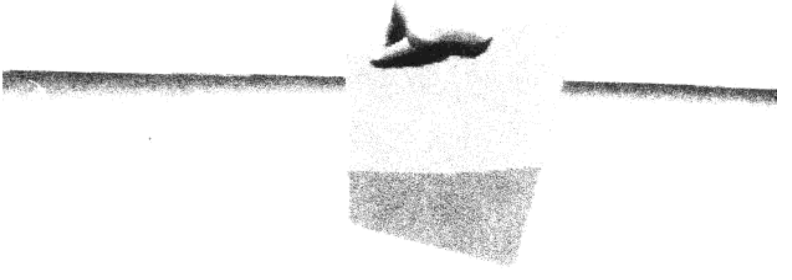

Figure 10

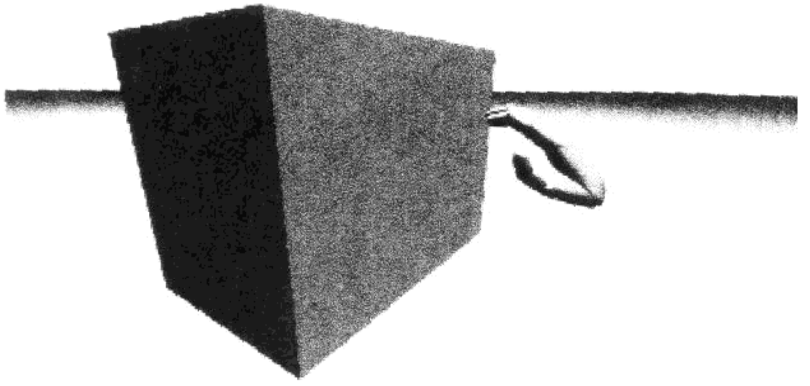

Figure 11

We want to evaluate this hybrid way of acting through extensive usability tests. In addition to this we are investigating the need for free-shape and unconstrained functionality in virtual space. Could this influence the real (buildable) design? Could this lead to a ‚VR-style" in design? An additional development is to integrate dynamic gesture recognition into voxDesign. This could dramatically improve the intuitive handling of the system. We try to involve the potential user as much as possible at all stages in the development work. For this reason, most of the research are the result of multi-disciplinary university courses. This has two major benefits: Firstly, there is an immediate and constant feedback of research results; and secondly, the students are confronted with state-of-the-art technology. Finally, the ethical and social questions that arise from VR are just as much an integral part of our work. We cannot and do not want to reject these questions.

5 Acknowledgements

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