*The original paper is published as: B. de Vries, H.H. Achten. What offers Virtual Reality to the Designer. In: Proceedings of the int. Conference on Integrated Design & Process Technology, Berlin, Germany, july 6-9, 1998. This paper is also available in PDF*

# What offers Virtual Reality to the Designer

## 1 ABSTRACT

Virtual Reality being a relatively new technology receives much attention in scientific research as well as in public news media. In the first case because of the technical problems that still have to be solved to offer the functionality and performance required by the application developers. In the second case because of the appealing interface between the application user and the computer system.

Design in general and especially architectural design has a long-standing tradition in solving design problems by mixing artistic and scientific approaches. Research has resulted in design theories and methodologies in order to better understand the design process and from that to improve the quality of the designed product.

Before applying Virtual Reality as an enabling technology for design, the characteristics of the technology and of the application must be specified. This is not an easy job since VR is not yet very 'stable' and design is a very complex process. From the knowledge and experience in the Calibre research group a first draft of a specification is presented so that we can draw some conclusions on the applicability of VR for design.

## 2 CHARACTERISTICS OF ARCHITECTURAL DESIGN PROBLEMS

The nature of design problems has been subject of prolonged study, starting in the early 1960's (Cross 1984). They are generally characterized as 'ill-defined' (Ibid., p. 145-166), or even 'wicked' (Ibid., p. 135-144), indicating for example a lack of explicit procedures for getting results, a lack of hard criteria for testing solutions, a large number of possible solutions to a problem, etc. Since typical design problems can not be solved in one run, the design process usually is lengthy and iterative. The study of design has been undertaken from a number of perspectives: from the design disciplines themselves, in order to achieve understanding of the actual design process in, for example, architectural design and industrial design; from the perspective of computer science, with a focus on design aid systems, the use of artificial intelligence in design, expert systems, etc.; and from the perspective of design research, with a focus on design as a general cognitive activity (Oxman et al. 1995).

In the domain of architectural design, characteristics of design are related to the complexity of the design task (encompassing many levels of scale ranging from structural details to urban design), the design context (varying amounts of participants with different mandates and conflicting interests), and complexity of the design process (open and flexible). Furthermore, the knowledge available to solve (sub)problems in architectural design varies considerably in quantity and quality (Heath 1984, p. 55). All these characteristics point out that architectural design cannot be undertaken in a general problem solving manner. During the long tradition of architectural design, the discipline has generated various approaches to tackle the problematic properties of design. A large number of these concern the use of prestructured solutions to general design tasks. Rowe (1987, p. 80-91) identifies so-called 'heuristics' which aid in constraining the possible solutions to a design problem, and which indicate ways of solving the task. Distinctions are made between "anthropometric" and "literal analogies" (transferring properties of an example to the design problem at hand), "environmental relations" (taking constraints from the immediate context of the design problem), "typologies" (generalized complete solutions for particular tasks), and "formal languages" (additional constraints relative to some style).

The current paper discusses design from the perspective of Computer Aided Architectural Design (CAAD). Research in CAAD has a long history, focusing on almost every aspect of design. In this paper we will focus on innovative design support that addresses the design approach of architects. Such innovative support must deal with the heuristics mentioned above, since a significant amount of architectural design knowledge is incorporated in them. Design support tools need to resemble such heuristics and design techniques, or that at least enable working with them. Nevertheless, it is also necessary to note that design tasks are becoming increasingly more complex (number of specialists, requirements, norms, technologies, etc.) and that they have become increasingly more difficult to solve with current heuristics. Therefore, it is necessary to focus on new techniques as well. In general terms, issues that need to be addressed in innovative design aid systems are: creation of form, design reasoning and inference, communication, kinds of representations, and design techniques and heuristics.

In our opinion, Virtual Reality (VR) technology can play an important role to assist and support the architect in both existing and new ways to deal with design. In order to identify the possible contribution of VR in design aid systems, we will compare it with the current CAAD paradigm. This enables us to highlight the particular properties of VR and to point out its advantages over other approaches. In order to do this, it is necessary to establish a list of aspects on which to compare the CAAD and VR paradigm. This is discussed in the next section.

## 3 ASPECTS OF ARCHITECTURAL DESIGN AID SYSTEMS

Aspects for CAAD systems can be derived from general software development. Sommerville (1992, p. 66) proposes five classes of requirements which are termed ‘viewpoints’:

1. Functional viewpoints: the functionality of the system. Bounding viewpoints result from the actual use of the system and defining viewpoints result from general considerations that can not be directly inferred from the actual use of the system. Examples of functional viewpoints are: client requirements, hardware implementation, kinds of documents used, precision/accuracy of work, kinds of hardcopies, enable conceptual design, support current norms and laws, evaluation functions, speed of feedback/result, etc.
2. Non-functional viewpoints: constraints that do not primarily influence functionality. Examples are cost, security, safety, reliability/robustness, efficiency, etc.
3. User viewpoints: information concerning the user of the system. Examples are skilled or novice designers, particular profession in construction industry, visual representation, ease of learning, etc.
4. Data viewpoints: information concerning the data structures and data flow of the system. Examples are model database, information handling, communication, knowledge-use, exchangeability, etc.
5. Service viewpoints: information concerning use and maintenance. Examples are hardware/software maintenance, (remote) updating/diagnostics, low tech maintenance, etc.

Since the interest of the current paper is in support of the architectural design process, viewpoints (2), (4), and (5) will not be considered. The functional viewpoint (1) will be defined in terms of tools, production aim, and representation. The user viewpoint (3) will be more narrowly defined in terms of interface technology. In this manner, the aspect of functional viewpoints deals with *what* a design aid system should be able to do, and the user viewpoint deals with *how* a design aid system should do that.

In order to answer the question stated in the title of this paper, the design function requirements and the VR interface possibilities will be related and evaluated in section 5.

### 3.1 FUNCTIONAL ASPECTS

The present discussion of functional aspects is narrowed down to three categories: tools, production aim, and representation.

*Tool aspects* deal with various kinds of functionality that design aid tools can have. Schmitt (1990) distinguishes between four classes of computerized tools for architectural design. They can be viewed as stating four different kinds of functionality in terms of design support: generic tools: tools that perform a given task regardless of its content (*e.g.* word processors, drawings programs, hypermedia, etc.); parametric modelling tools: tools that incorporate design knowledge in structures which allow a range of values for their parts (*e.g.* classical orders in facades, stairs, etc.); prototype editors: tools that incorporate design knowledge of complex objects with particular properties (*e.g.* tools for particular kinds of houses, buildings, building parts, etc.); and shape grammar generators: tools that generate objects belonging to specific form-languages (*e.g.* Palladian villa's, Victorian houses, etc.).

*Production aim* concerns the required documents that need to be produced during the design process. These are linked to the stages of the design process. These stages can be viewed as stating seven kinds of functionality in terms of required documents. Schmitt provides the following schematic subdivision of the design process: (1) program development, (2) schematic design, (3) preliminary design, (4) design development, (5) contract documents, (6) shop drawings, and (7) construction.

*Representation* deals with relevant representations that a design aid system must support: two-dimensional (2D; representations such as plan, section, facade), three-dimensional (3D; *e.g.* perspective, isometric or axonometric projection), static (drawing of desired state), and dynamic (time, behavior, interrelationship).

Although the particular kinds of tools, production aim, and representation mentioned here are specific for the discipline of architectural design it seems possible to generalize these requirements to other design disciplines. It can be claimed that they also make use of pre-structured knowledge in various degrees which offers functionality, that their processes are ordered in design phases which yield specific documents, and that they make use of a limited set of representations to proceed during the design process. To summarize, the functional aspects are:

***TOOLS***

1. Generic functionality [multi-purpose, wide range of application].

2. Parametric functionality [structures that encode standardized routine knowledge/design].

3. Prototype functionality [structures that bring coherence to large relatively complex wholes].

4. Shape grammar editing functionality [implementation of formal languages].

***PRODUCTION AIM***

5. Brief [stated list of requirements of the design in terms of spaces, cost, time, parties, mandates, etc.] .

6. Schematic design [sketch design showing principal solution of the design].

7. Preliminary design [worked-out drawings that show most design decisions].

8. Contract documents [drawings and text for putting out to tender].

9. Shop drawings [detailed drawings of the whole design].

10. Construction drawings [specification of the construction process of the design] .

***REPRESENTATION***

11. 2D [plan, section, facade].

12. 3D [perspective, isometric, axonometric].

13. Static [drawing, desired state].

14. Dynamic [time, behavior, interrelationship].

These aspects of functionality are relevant for design support as discussed in section 2. The tools deal with heuristics and design techniques; production aim deals with the practice of design and the design process; and representation deals with the way design problems are treated throughout the design.

#### 3.2 INTERFACE TECHNOLOGY

The user viewpoint is narrowed down to interface technology. Coomans (1997) establishes the following aspects of user interface: (1) interaction: interactive manipulation of the design in ways that are natural for the architect and which do not draw attention to the handling of the interface; (2) immersion: three-dimensional real-time spatial experience of the design; (3) simulation: visual, acoustic, and haptic simulation of the design for relevant feedback of design decisions; and (4) visualization: visualizing information that is non-visual by nature (such as heat transfer, cost, structural forces, etc.).

To summarize, the interface technology aspects are:

1. Interaction [real-time feedback, natural interface, unobtrusive design actions].
2. Immersion [spatial assessment, three dimensional representation, real-time movement].
3. Simulation [calculation and rendering of (physical) properties of the design].
4. Visualization [representing non-visual information in a visual manner to provide feedback].

These aspects of user interface are relevant for design support as indicated in section 2. Interaction refers to the cognitive aspect of the design process, where the architect is engaged in a time-consuming process of iterative cycles of design. In the early stages of design, many ideas are generated and tested in a fast manner. Often these are created by means of sketching, where the rate can exceed 20 drawings per hour (McCall, Johnson and Smith 1997). The point here is that design is a process which requires a large degree of interaction if it is to be well-supported in a design aid system. Immersion deals with the spatial appreciation of design decisions in the process. Simulation deals with the consequences of design decisions, and visualization refers to the fact that architects predominantly use visual information and are capable to assess decisions visually more able than for example, numerical information.

### 4 A COMPARISON OF CAAD AND VR DESIGN SYSTEMS

Before elaborating on the functional requirements in relation with Virtual Reality, CAAD tools are introduced since they offer a reference enabling us to compare the current status of design systems with a proposed future system.

The functional and interface aspects lead to eighteen aspects on which to compare current CAAD tools and the proposed VR system. Before doing so, we will define the CAAD and VR paradigms.

- *THE CAAD PARADIGM*

A CAAD system is a computerized system that produces engineering and design drawings. Models are constructed on the basis of primitives using 2D-drawing analogies from the design practice (lines, symbols, hatching, building elements). The interface is controlled by hand-manipulations (mouse, keyboard) on a flat plane (move, drag, pull-down). Domain knowledge is coupled to an entity-level database. The CAAD paradigm is exemplified in systems such as AutoCAD, Arkey, Mircostation, etc.

- *THE VR PARADIGM*

A VR system is a computerized system that produces engineering and design three-dimensional models. Models are constructed using solid modeling techniques and scale-modeling analogies from the design practice. The interface is controlled by the body (glove, head, position, movement) in space (move, drag, scale, mould) featuring immersion and real-time feedback. Domain knowledge is incorporated in both the design process and in a hierarchic multi-level database. The VR paradigm is exemplified in systems using head-mounted displays, data gloves, pointer devices, real-time rendering and textured surface models.

Since many aspects are not stated quantitatively, the comparison of CAAD and VR design systems goes not further than stating between ‘+,’ ‘-,’ ‘0,’ and ‘n/a.’

- ‘+’ Means that the paradigm meets the aspect and that it in fact enhances it.
- ‘-’ Means that the paradigm does not meet the aspect and that it in fact obstructs it.
- ‘0’ Means that the paradigm neither enhances nor obstructs the aspect when implemented in the paradigm.
- ‘n/a’ Means that the paradigm does not feature the technology or aspect, and can therefore not be assessed.

The comparison results in two matrices, characterizing VR technology in terms of design function and interface, and CAAD technology in terms of design function and interface. The first column of the matrices states T(ools), P(roduction aim), and R(epresentation). The first row states In(teraction), Im(mersion), Si(mulation), and Vi(sualisation). The T(ools), P(roduction aim) and R(epresentation) rows are further identified according to section 3.1. The gray accented rows identify best performance of the technologies in design support.

**Table 1 Design function - Interface matrix applying Virtual Reality technology**

| | | In | Im | Si | Vi |
|---|---|---|---|---|---|
| | **Gen** | - | - | - | 0 |
| **T** | **Par** | 0 | 0 | - | + |
| | **Prot** | + | + | + | + |
| | **Shap** | + | + | 0 | + |
| | **Brief** | 0 | - | 0 | 0 |
| | **Sch** | + | + | + | + |
| **P** | **Pre** | + | + | + | + |
| | **Cont** | - | - | - | - |
| | **Shop** | - | - | - | 0 |
| | **Cons** | - | - | + | + |
| | **2Dim** | n/a | n/a | n/a | n/a |
| **R** | **3Dim** | + | + | + | + |
| | **Stat** | - | 0 | 0 | |
| | **Dyn** | + | + | + | + |

**Table 2 Design function - Interface matrix applying traditional CAAD technology**

| | | In | Im | Si | Vi |
|---|---|---|---|---|---|
| | **Gen** | - | n/a | n/a | + |
| **T** | **Par** | - | n/a | n/a | + |
| | **Prot** | 0 | n/a | n/a | + |
| | **Shap** | 0 | n/a | n/a | n/a |
| | **Brief** | - | n/a | n/a | - |
| | **Sch** | 0 | n/a | n/a | - |
| **P** | **Prel** | 0 | n/a | n/a | 0 |
| | **Cont** | - | n/a | n/a | - |
| | **Shop** | - | n/a | n/a | + |
| | **Cons** | - | n/a | n/a | + |
| | **2Dim** | 0 | n/a | n/a | + |
| **R** | **3Dim** | 0 | n/a | n/a | 0 |
| | **Stat** | - | n/a | n/a | + |
| | **Dyn** | n/a | n/a | n/a | n/a |

## 4.2 COMPARISON

VR technology is relatively young. It has not been applied very much in design aid systems but almost exclusively for presentation when the design is finished. Therefore there is no established standard of VR-based design systems, which makes assessment difficult. Given the appeal of new technologies, it is tempting to state that all aspects will profit from application in VR. This however, is most probably incorrect. Experience from the past has learned that efforts to realize design systems for everything and for everyone have failed. The practice of architectural design necessarily leads to specialized and well-understood design systems, which cover only partial stages of the design process. Furthermore, it is necessary to point out that the list of requirements is largely based on current practice and state-of-the-art of design aid systems. They do not necessarily reflect state-of-the-art in the near future. This issue will be addressed in the concluding section.

From the Design function - Interface matrix applying Virtual Reality technology respectively CAAD technology, the following conclusions can be drawn:

1. VR technology shows the best performance in the early design stage, using tools to create and evaluate (abstract) design models based on a three dimensional dynamic representation.
2. CAAD technology shows the best performance in the final design stage, using a 2 dimensional representation.

3. CAAD tools offer good visualization of the design but very poor natural interaction with the user. CAAD does not feature Immersion and Simulation.
4. VR technology is not suitable for production of the traditional documents used for information exchange.
5. VR has the most potential in those areas where CAAD has a poor performance.
6. Generic and parametric design tools are not adequate for Virtual Reality.

A danger of exploiting new technologies in current practice is that only existing functions are implemented. More challenging and probably more promising is the research for new functions that emerge from new technology such as Virtual Reality. Apart from prototyping and shape grammars, new tools are required to implement the interface between the design system and the designer. These tools are based on the use of three dimensional metaphors as opposed to the two dimensional metaphors (like Windows) of the user environment of current computer systems. Especially the development of these metaphors in combination with the peripherals to establish the man-machine interface will contribute highly to the adaptation of the Virtual Reality paradigm.

Relating the traditional production aim with a new technology may result in wrong conclusions. It is concluded that VR shows poor performance in producing documents. In stead of trying to solve this shortcoming, research should focus on elimination of the need for these documents. Thus the means should be developed to present information using versatile digital media and to transfer information using electronic networks. Again, the availability of these means will contribute highly to the adaptation of the Virtual Reality paradigm.

## 5 RESEARCH ON VIRTUAL REALITY

At the Architectural Design Systems group of the Eindhoven University of Technology, a comprehensive research program is established called VR-DIS. The acronym VR-DIS has two meanings. From a technical point of view VR-DIS stands for Virtual Reality - Distributed Interactive Simulations. From the application point of view VR-DIS stands for Virtual Reality - Design Information System. The design system architecture is divided into three layers: user interface, information storage and computer system.

Research and development within the program are focused on creating interfaces for access to design information, rather than focusing on the computer system itself. Education in the group is based on experiments and research on the user interface. Since Virtual Reality is chosen as the preferred technology to implement the interfaces, this will yield theoretical and more practical results on the impact of this technology in architectural design.

The current status of the research is that the VR equipment is mainly used for visualization with limited interaction with the user and limited simulation of object behavior. About seven Ph.D. research projects are in progress to contribute to the development of a VR design system that meets the requirements as discussed in this and other papers (van Zutphen and Mantelers 1996; de Vries et al. 1997).

## 6 CONCLUSION

As a contribution to discussion at the workshop the following discussion statements are proposed:

1. VR will replace the 2D user interface of traditional CAAD tools. The traditional interface in CAAD tools is obstructive and forces the user to think on how to achieve something rather than what to

achieve. VR offers the opportunity to use skills already used and practices in daily use.

2. VR is the 'natural' environment for prototyping and for creation of shapes. Immediate feedback, spatial representation of objects, and ease of creating and changing objects better support articulation of the designers intentions.
3. Designers have to design their own (3D) environment to execute design activities. Each design discipline has its specific set of heuristics and design techniques that match their practice. These aspects are reflected in the VR-environment.
4. Experiencing design behavior is only possible using VR. Design behavior such as thermal or acoustic isolation, structural stress, safety, cost, etc. are represented as colors, sounds, and diagrams. These can be directly mapped on the design object in a VR-environment thus giving instant feedback to the designer.
5. VR technology, addressing general cognitive abilities of designers, enables the combination of 'artful' and 'intuitive' design heuristics with solid engineering knowledge and practice. It allows for a more ubiquitous support of the 'art of the design.'

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