

## Computational design - Simulation in virtual environments

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**Computational design : Simulation in virtual environments.**

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**Abstract**

Rapid developments in technology, growing number of regulations, increased complexity in building products and processes and high quality demands towards results, are all examples of developments which manoeuvre architects in a direction with the potential danger that design solutions will be more and more based on intuition or narrowed down to just morphological and easthetical issues. Although these two issues are essential for design, the adaptation and integration of other disciplines are needed regarding to the developments mentioned above. Criteria like costs, structural and thermal behaviour and many other aspects should be taken into account, preferably in the early stage of design and not just during analysis later in the process. The need for proper design supporting tools to handle complexity is inevitable.

This paper is about the research and development of a framework of supporting interrelated tools. The framework is based on the use of a fully digital prototype and is called VR-DIS, an acronym for Virtual Reality Distributed Interactive Simulation. The concept is based upon the awareness and integration of three key technologies: virtual reality, simulation and product modelling.

**1. Introduction**

Today, the benefits of computer aided tools and techniques are well known in the building industry. But unlike other industries, for example the automotive and aerospace industry, the use of digital prototypes for simulation, presentation, evaluation and planning are not widespread and accepted within the building industry. In architecture, a scale-model, is merely used as a physical prototype for evaluating and communicating form and texture. This is very limited compared to the functionality of digital prototypes. There is another shortcoming, the step by step preparation and evaluation of physical prototypes is very time-consuming. Fully digital prototypes overcome this limited stepwise refinement [Haas]. Simulation, evaluation and modification can take place within seconds through a highly interactive user interface. Instead of time consuming refinement loop iterations, interactive multidisciplinary work is made possible. The benefits are clear: the shortening of the design cycle and the quality improvements due to enhanced information.

**2. The VR-DIS platform**

VR-DIS is an acronym for Virtual Reality - Distributed Interactive Simulation. The VR-DIS platform is a innovative instrument to support research in the multi-disciplinary process of design. VR-DIS aims to address, professionals and non-professionals, including architectural students. The platform enables users to explore, analyse and evaluate various aspects of (sub)design.

The VR-DIS platform is a follow up of earlier research done by a collaboration of the Building Information Technology group and Institute Calibre at Eindhoven University of Technology.

The final goal is to increase effectiveness and quality of design by offering a digital prototype that can be manipulated and explored real-time.

The concept behind VR-DIS is based upon the senergy of three key technologies: Product modelling, Virtual Reality and Simulation.

**3. Keytechnologies****1. Product modelling in design**

In order to discuss design, the entities, their properties, their relationships, and their behaviour among them need to be described. Design applications demand a flexible data description scheme that is easy to modify. Independent multiple views of design-team members result in partly independent data-models. Together the different models form a overall data-model of a design, the building-model [Leeuwen94]. A consistent operational building-model is still an utopia. The results from various related attempts to define a overall architectural information model have still a long way to go before implementation within the VR-DIS framework could be considered. For most research it seems expectations were set to high and not very realistic to achieve within the proposed time scale.

It is our believe that an overall top-down integrated product data model is a fiction. This because the need for information is not static but dynamic. It is dynamic for several reasons: the fragmented organisational structure of the construction industry where every company has it's own policy and standards for information technology [Atkins], the ill-defined, complex and dynamic process of design and the ever changing technology, to name a few.

Adapting new technologies means reorganisations, new responsibilities, new tasks, hence changing demands for information and communication. In management terms this phenomena with all it's consequences is known as Business Process Redesign.

Also the enormous amount of information within a overall information model is often underestimated: to give an example, the basic geometry description of a Boeing aeroplane alone takes tenths of gigabytes!

In this research a more pragmatic bottom up approach has been chosen based on existing standards and data exchange protocols as much as possible. It is according the business rule "Think Top Down, do Bottom Up". In this sense our models are more like document models instead of view-models and aspect-models [Nederveen]. The drawback of course is the need for several conversion tools for data exchange and workarounds to avoid loss of information and to keep information consistent.

A possible solution could be the use of feature based modelling which is subject of current research [Leeuwen96].

## 2. Virtual Reality in design



Because most designers and architect are not a computer engineer, a natural and powerful userinterface is needed. Our earlier research [Smeltzer] showed to strength of Virtual Reality techniques as a foundation for creating realistic and interactive userinterfaces. The modelled building environment can be used to experienced and convey using modelling devices such as a 3D mouse, joystick or keyboard and display devices such as a head mounted display, stereo glasses, large screen stereo projection or a workstation-stereo screen.

During the last years VR technology was mainly used for computer visualisation and evaluation of architectural designs which were almost completed.

Examples of Virtual Reality research we did are:

- Several research projects involved design evaluation by (partly) immersive walk-through in non-existing buildings. Architect and principal walked through a virtual building discussing several design issues. Based upon their evaluation of the design, using the virtual reality system, a number of design improvements were made.
- Virtual furnishing by manipulating interior elements.
- Virtual way-finding for exploration the effect of signs in buildings and related safety aspects. For example the quality of 'exit'-signs and their position in case of fire.
- Simulation of lighting situations, bringing the knowledge lighting engineers into the process of design.
- Visiting and exploring virtual ancient buildings like the Taj Mahal in India.

The VR-DIS platform can be seen as an extension to our former VR-system. The main extensions are the support for early design and the increased functionality of behavioural simulation. Also from a more technical point of view, the modelling tools and software development tools have been greatly improved, due to financial support of the faculty. These improvements have resulted in much better performances.

Another extension is the usage of Virtual Reality techniques to create Virtual Environment which are used to validate the correctness of simulation models or design theories like constraint based design, component based design, design for production, to name a few. In fact, for historical reasons we continued to use the term Virtual Reality in VR-DIS, although instead of VR, VE from Virtual Environments would be more appropriate.

### 1. Simulation in design

The design process is an iterative and multidisciplinary process. Each participant has it's own view. For computational design these views are translated to view-models and because all views are related to the same design, the view-models are interrelated also. The set of interrelated view-models is called a overall productmodel as we have read above. For computational support it would be ideal to have a well defined unambiguous analytic model. But this ideal seems impossible to achieve. Therefore the question to be answered is whether there are no other methods available to study interrelated sub-designs in a virtual environment. An answer could be the use of simulations. Simulation is used in complex dynamic problems where exact analytic and mathematical methods are problematic and not feasible and the process of design is about solving complex dynamic problems.

Simulation is imitating the behaviour of a system by means of another system, which resembles the first system in certain aspects and therefore is a model of the first aspect [Roozenburg]. In this paper the simulation model is called a digital prototype

Simulation can be used in all phases of the design. Through simulation of the behaviour of a design model, instead of for example the use of rules of thumb, the problem solving capacity of the designer can be increased.

Simulation addresses the behaviour of building components. Classical arguments, for simulation, translated to our scope, are:

- physical scale model are too expensive and time consuming when several alternatives are needed for research
- real experiments, for example stress analysis or thermal comfort, can be dangerous
- unlike in other industries, it is impossible to build a first realistic prototype because normally every building is unique and therefore prototype and final design would be the same object.

It should be evident : simulation is more than just execution of calculations. Simulations can be based on a scientific theory or on experience. Computer simulation is only possible if a simulation model exist. This model can be a formal mathematical or product model, but also a informal model such as a diagram, a graph or even a written description of the behaviour of the system to be simulated.

The VR-DIS framework uses both formal and informal models.

#### 1. VR-DIS usage and requirements

The VR-DIS platform can be used for different aims, namely as an instrument for:

- Design decision support. For example by generating and comparing different alternatives
- Feasibility studies in relation with requirements, regulations, economics
- Enlarging the insight in the overall system. Decision in one subsystem can change items in another subsystem and have an impact in the overall system
- Sensibility research in causal relations. What is the effect of a certain alteration of one or more variables
- Support for design optimisation
- Study of real-time behaviour of building parts like construction, technical system, facade
- Support of co-operative workgroups and concurrent engineering.
- Verification of design theories to increase methodological knowledge

Besides the aims mentioned above, lowering the threshold of acceptance through the support of training and education of students and professionals is another goal of the VR-DIS framework. The next paragraph will explain this.

#### 1. Adoption of innovative technology

In general, the building industry is very reluctant as it comes to adopting new information technologies (IT). An important reason seems to be the lack of knowledge by the management about the advantages of innovations like virtual reality, digital prototyping, product modelling.

A problem is that IT is expected to enable humans to get a better understanding of the complexity of their surrounding world. On the other hand, IT will increase this complexity and thereby also in business terms, the uncertainty about unknown risks. Uncertainty is something managers try to avoid as much as possible. From this we can learn that the development of new technologies itself is not enough, the acceptance of these technologies is also a elementary condition. For acceptance, more knowledge about IT is essential. Rogers [Rogers] did research about the diffusion of innovations. His research showed that most respondents did not adopt new technologies based on results of objective scientific studies but on subjective evaluations from partners, 'near-peers' as Roger called them, who already used the innovative technology in question. This dependency between 'near-peers' suggest that the core of the process of diffusion is situated in the imitation by potential users from earlier adopters with whom the potential users have some kind of a relation.

To improve the adoption of new technologies in design we need to do two things. Students, the next generation designers, need to be taught about the (im)possibilities of IT. At the same time professionals need to be demonstrated the enormous potential of Virtual Reality, digital prototypes and other innovating information technology.

#### 2. VR-DIS Hardware and Software implementation

VR in teaching, training and research demands for professional development tools. The VR- tools used are: dVS and dVISE from Division Ltd and WorldToolKit (WTK) from Sense8. Both dVS and WTK are low level software libraries. There is a tendency to prefer dVS above WTK, therefore dVS and dVISE are explained more in detail.

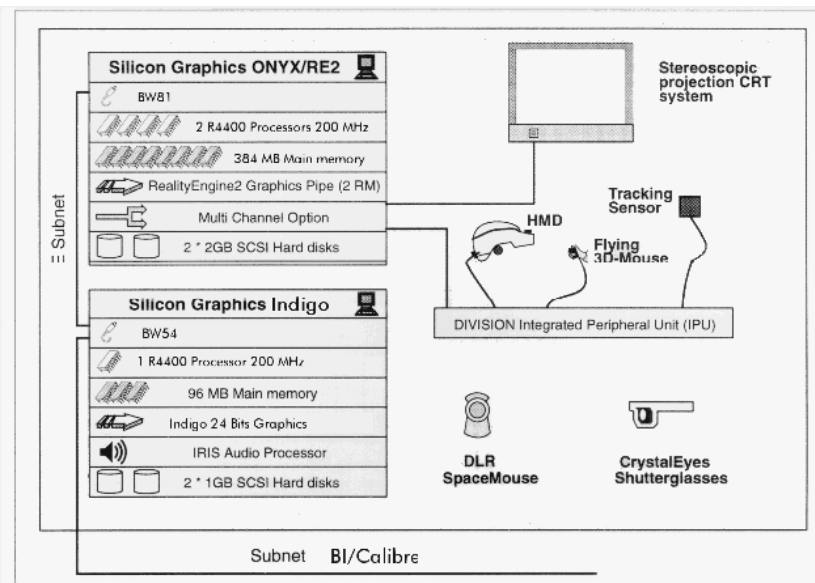
dVS can be thought of as a library of VR-functions, the VC-Lib, and a general purpose runtime module for VR-applications. The runtime module provides the core VR-functionality through a set of discrete services. The implemented services, known as actors, are: a visual server for real time rendering, a input server for reading user input, a physics server for simulation of forces like gravity and friction. A collision server for collision detection, an audio server for sound synthesis and a body server to interpret the user actions. Each actor is optimised for one service only. The library functions provide an extensive environment with full support for handling the runtime actors.

To gain a maximum of performance, the actors runs in parallel with each other and if desired on different machines. DVS also support extensibility, the existing set of actors can be scaled up with own developed ones.

dVISE is a Virtual Reality application on top of dVS. dVISE from Division Ltd is an interactive Virtual Reality authoring tool and is relatively easy to use. While dVS is used by experienced software developers, dVISE is used by colleges and students, one of our key targets, with less or no experience at all. No software development knowledge is needed, although some experience would be helpful. dVISE has an object oriented like interface which is easy to learn and powerful to build hierarchical object structures.

To create the various models besides the above mentioned tools, the following simulation, modelling and Rendering software is used: Modelgen II, Autocad R13, 3D Studio Renderer, ARC+, IRIS Performer, LightScape.

We are still looking for a suitable Database Management system.



To enable users to experience and interact with 3D virtual environments input and output peripherals are needed. The available input devices for tracking position and orientation are: 3D mouse, normal and flying joystick, Polhemus Fastrak tracking system.

The available display devices are: Head Mounted Display, stereo shutterglasses, large screen stereo projection and workstation-stereo screens.

For spatial sound an Acoustetron II is present.

The computer systems forming the VR-DIS framework are a range of Windows NT based workstations, several Silicon Graphics workstations (Indigo 2 High Impact and Indigo 2 Extreme) and a state of the art visualisation machine (Onix RE2).

### 3. Current Research in VR-DIS

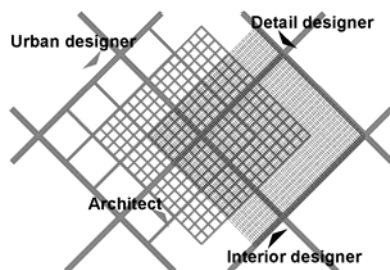
Different aims of VR-DIS are mentioned earlier in this paper. These aims can be applicable in several main areas of interest. We distinguish three categories:

1. The concept of VR-DIS as a subject of research. Most projects are belonging to this category. Examples are research for natural user-interfaces, design information structuring.
1. VR-DIS as a electronic design assistant. Here the VR-DIS platform, as far as it is operational, is used as an aid in design projects. These kind of projects are in fact test-cases for correctness and functionality of the VR-DIS concept.
1. VR-DIS as an simulation aid for other research. VR-DIS is a powerful tool to create Virtual Environments which can be used as a virtual laboratory for all kinds of research. For example to test signs for way finding in buildings or simulation of physical or chemical processes to name something completely different.

Within each category several research-projects are defined. To give a better understanding, some of these projects are explained here. For more detail we refer to the references and our WEB Side : <http://www.calibre.bwk.nl/>.

#### The project "Generic representations and the Generic grid" .

A Generic grid [ Achten] is a hierarchically ordered set of grids whose modules are whole multiples of each other. It provides an abstract structure for describing designs for analytical and design purposes. Each grid has its own level of scale and are used to describe elements and structuring design. By assigning elements to specific levels, various design disciplines such as urban designers, architects and interior designers can be identified as dealing with these grids. Because grids are interrelated, design decisions on one grid affects other levels.



The generic grid offers a principle to decompose and aggregate design elements. Grids enable the support of a logical zoom, that is, the level of detail of the representation of building elements is relative to the working scale. A logical zoom is a powerful technique for presentations in Virtual Reality, for performance as well as for generating realistic images - farther away means less detail.

For now, the implementation and testing is done in AutoCAD using AutoLisp. The next step will be the integration into the VR-DIS platform.

#### The project "lighting simulation in interactive 3D-environments"

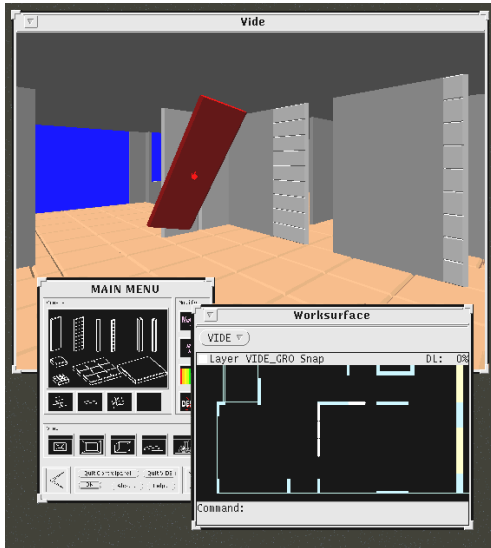
The impact of design choices upon the use and the effect of artificial lighting in architectural situations can be very significant. In many cases however the influence of these choices on the daylight situation can be even more dramatic. This research is about the

definition and implementation of interactively design decisions support for lighting within the VR-DIS framework [Roelen]. A lighting-simulation program was selected that could combine calculations for artificial and daylight and at the same time could output 3D-models with the results of these calculations attached.

Two methods of attaching the results of lighting calculations to 3D-model data for interactive visualisation were studied: vertex colours that represent the illumination of that point and generated colour-textures based upon the surface material and the calculated illumination-distribution.

Both methods can only be used to simulate and visualise the diffuse part of the result of the illumination. Accurate visualisation of effects such as highlights and glare will be subject to a later stage of this research.

### The project "Prototyping of Design in Virtual Reality"



Four problems underlying the inability to use CAD systems in the early, conceptual phase of the design process have been identified. They are prototyping capability, visual reasoning, interactivity and evaluation support. Design prototyping [Coomans] as a technique for support of early conceptual design will have to address these problems. The research does not only concentrate on the theoretical issues but also on the technical concepts and problems.

A prototype, VIDE, was built to get a better understanding of the issues involved. VIDE uses mixed plan-views and rendered perspective view. The prototype demonstrates that Virtual Reality techniques can be used to create an interface that allows modelling in an instinctive way through the sensing of simple user's gestures.

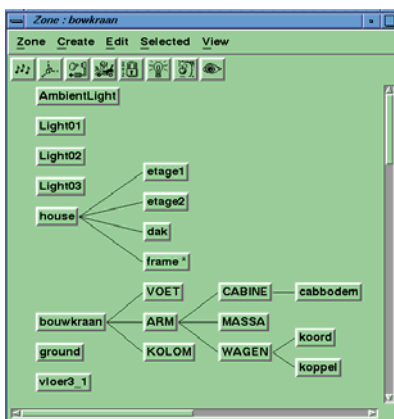
On the other hand, still a number of (technical) difficulties have to be resolved for example the accurate tracking of position in 3D environments.

### The project "Feature based modelling"

This project aims at developing a framework for defining and creating information models for architectural application, using a Feature-based approach, which have the important properties of flexibility and extensibility [Leeuwen96]. A Feature is a collection of high-level information defining a set of characteristics or concepts with a semantic meaning to a particular view in the life-cycle of a building. Feature types are: Form-, physical-, procedural-, context- and life-cycle features. The research describes a basic classification of architectural Features types, which is mainly based on a survey and analysis of building- and design-related information.

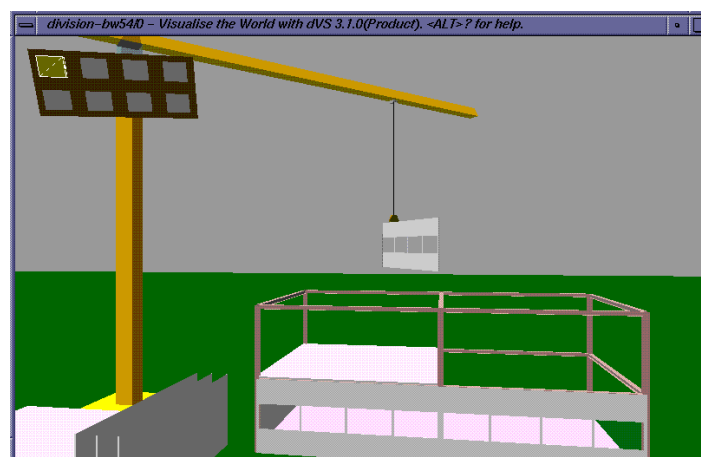
The development of a pilot-system, called a Feature-Based Modelling Shell, for computational support is expected to indicate that practical implementation of this framework is possible and may result in a powerful tool for design-support.

The framework is not restricted to information from design-stages only, but allows information from the complete life-cycle of an architectural artefact to be defined and modelled. The framework also contributes to the development of more flexible ways of communicating design- and building-data between parties and across disciplines.



Information modelling in the VR\_DIS framework requires an approach that allows for easy customisation of data-definitions and software components. The flexibility and extensibility of the Feature-based approach to seems to be very promising as an alternative to the traditional STEP-based product modelling methods.

### The project "Simulation of building crane"



The simulation of a building crane on the construction side using the VR-DIS framework has numerous advantages. It can be used to study and improve both the

layout of the side as the planning of logistics - 'just-in-time' concepts can be tested.

In practice, under pressure of time, often only one layout is planned. The use of R-DIS the planner can generate more variants, and at the same time taking more aspects into account.

Also the simulator can with some extensions be a training aid for crane-machinists.

Next step in this research will be the virtual assembly of prefabricated facades.

### The project "Conjoint measurement in a virtual environment"

Conjoint analysis, also called stated preferences analysis, involves the use of designed hypothetical choice situations to measure individuals' preferences. The results of the analysis are used to predict individuals' choices in new conditions [Dijkstra]. In this research product profiles are generated in a virtual environment and respondents are asked to choose in that virtual environment the product profile they prefer. The virtual environment can be for example a shopping centre or the working place within an office. Advantages of a virtual environment is a better control of the analysis, the usage of 'real' environments is often too expensive or impossible, and the possibility to include measurable attributes such as time and sound. The importance of VR is obvious in new product research, as a new marketing tool and as bringing realism in consumer interaction.

### Résumé

The last project is a perfect example of the usage of VR-DIS as a simulation aid for other research (category 3). The projects 'lighting simulation' and 'simulation building crane' increase the functionality respectively usability of the VR-DIS framework as a design assistant (category 2). Within the other projects the theories and assumptions of the framework are subject of research.

#### 1. Discussion

The VR-DIS framework is a powerful instrument for supporting design including the full building life cycle. VR-DIS enables research on issues as decision support, feasibility, behaviour of building parts, sensitivity of design variables, communication and co-operative workgroups. Using VR-DIS, professionals and non professionals can get a better insight in the multidisciplinary process of design. A design-Methodist can use the framework to evaluate his or her theories and models of design because of the flexible and natural interface.

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