14. Computational Design Research

The VR-DIS Research Programme

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14.1 Introduction

In 1995, when the previous Design Research in the Netherlands Symposium was organised, the Department of Building and Architecture consisted of four groups working in design research and design computation: Vormleer, the Design Methods Group (GOM), the Bouwinformatica (Building Informatics) Group, and the research institute Calibre.
In the period 1997-1998 this situation changed: GOM and BI merged to form the current Design Systems Group, and Calibre became a commercial business under the TUE holding. A new research direction was formulated for Design Systems, based on the existing expertise particularly in design support, CAAD, VR, and design methods. The new research programme was titled VR-DIS. In this paper we will outline VR-DIS, discuss a number of design research approaches that underlie the philosophy of VR-DIS, and present results and ongoing work in the research programme.

14.2 VR-DIS

Computational design support is still in its infancy. Among various problems that can be seen, we note, in particular, the following:

- Most computer applications are task specific and data-exchange between them is difficult.
- The human-computer interface can be greatly improved to become a fluid medium of expression in the design process, which it is not today.
- Design representations and design knowledge in the various disciplines are understandable in those disciplines themselves but difficult to exchange.

The Bouwinformatica Group and the Calibre Institute had gathered considerable expertise in computational design support, most notably in the areas of visualisation and Virtual Reality technology. From this basis, the following future situation was hypothesised as a context for research:

- Computational applications that aid in the design of inherently spatial objects (e.g. buildings in Architecture, products in Industrial Design, HVAC systems in Engineering, etc.) will move toward a spatial metaphor.
- Design knowledge and information of the design stored in the computer will have spatial representations.
- The motoric and cognitive capacities of designers in everyday life and professional life can be mapped more easily on spatial metaphors than others.

In short, we believe that VR can become the key representation not only for electronic design media (VR-based CAD), but also for replacing the current two-dimensional desktop metaphor. For the development of such a comprehensive use of design knowledge in a VR environment, the VR-DIS programme was defined in 1998.

VR-DIS is an acronym that has two meanings: Virtual Reality – Design Information System, and Virtual Reality – Distributed Interactive Simulation. The first acronym refers to the visualisation of design knowledge and outcomes of design actions in the building design. The second acronym refers to multiple users on different locations engaging a model in Virtual Reality.

If we want to achieve spatial design representations both of the building design and the designer's knowledge, then we need to have access to this knowledge. For this purpose, the VR-DIS research programme is formulated department-wide. The goal is to investigate and incorporate the knowledge of groups such as Building Physics, Construction Management, Architectural Design, Urban Design, etc. into the VR environment.

The core activity lies with the Design Systems group, because in this group the key expertise on VR, formalisation of design knowledge, design research, and software development is present. People from Design Systems are involved with VR-DIS projects that are located within the various groups of the Department of Building and Architecture. Since the Design Systems group is involved in the VR-DIS programme to a great extent, the groups' own research programme has also been named VR-DIS. Also, there is continuous research collaboration between Design Systems and the Calibre business. To make the picture complete (although perhaps less clear), the work of the Design Systems group is situated within the DDSS programme: Design Decision Support Systems, in which Design Systems co-operates with the Urban Planning group. In the framework of DDSS, a bi-annual international conference called "Design Decision Support Systems in Architecture and Urban Planning" is organised.

14.3 Research in VR-DIS

The end goal of achieving a VR-based design aid system is planned in a three-stage development. Each following step requires partial completion of the previous one:

1) System I: Interactive design system for one designer. This concerns study of design support for the total life-cycle of a building or the built environment. Aspects are: user interface, immersive design tools, knowledge representation, consulting design knowledge, checking against standards and rules, and simulating product behaviour (see Figure 14.1; left).
2) System II: Networked distributed multi-disciplinary design system. Study of the requirements for multiple users working on the same design in VR. Aspects are: user representation, different user views, consistency of design data, management of design and process, collaborative design, and (a)synchronous communication (Figure 14.1; middle).
3) System III: Networked interactive evaluation system, which also takes into account future user reactions. This concerns the study of user behaviour in a design. Aspects are: measurement of user behaviour in building and urban design, evaluation of behaviour and information handling, agent theory, and conjoint measurements (Figure 14.1; right).

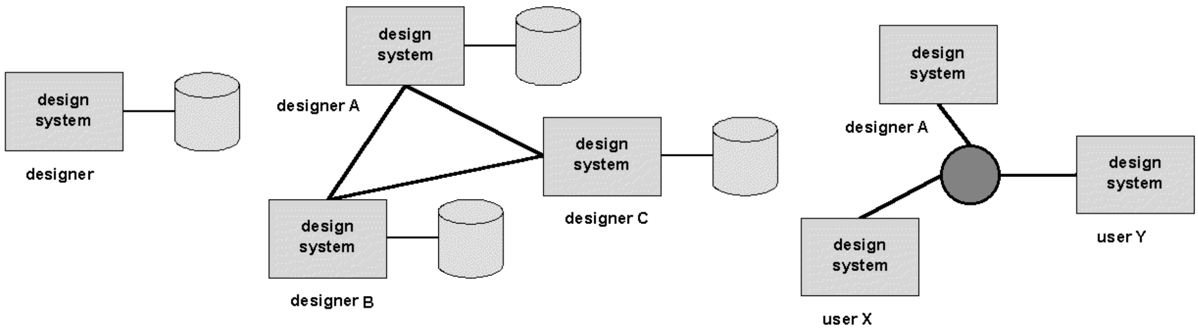

Figure 14.1: Three systems in VR-DIS.

At the moment, a number of prototypes have been developed that deal with issues for system I: the Feature Manager, the Constraint Solver, ILSA, WEDA, and DDDoolz. Projects dealing with systems II and III have more or less recently started.
In the next sections, we will present some broader issues that are connected to the VR-DIS research.

14.3.1 Ph.D.'s in VR-DIS

In the context of VR-DIS, numerous Ph.D. research projects have been formulated, each concerned with a specific aspect of the research discipline in which it is located (e.g. building physics or construction management) and the connection with VR-DIS. Although the ultimate aim is to yield results integrated in a VR-based system, the main goal of the Ph.D.'s is to establish the theoretical work that will make it possible to further use the results in the VR-DIS programme. In section 14.4 the Ph.D. projects are summarised.

Data model: Feature Based Modelling

For computational design support to be realised, it is necessary to have an information model that can capture the richness of design information. In Design Systems, this information model is based on Feature-Based Modelling (FBM). The foundations for this have been established in the doctorate thesis of Jos van Leeuwen (1999). First a modelling tool was developed to support this method of data modelling. This so-called "Feature Tool" was implemented on a relational database. In a second development, the relational database was replaced by a Feature Manager that is based on an Object Oriented database and which greatly resembles the Feature Model structure defined by van Leeuwen.
FBM has the advantage that it can capture information in various degrees of abstraction. The work of van Leeuwen was aimed at giving it additional flexibility and extensibility so that the dynamic nature of design with its continuously changing datamodels can be described. In our research on the user requirements for a design support system, we have extended FBM to analyse design processes.

Research method: case study

With the FBM approach we have the main framework to formalise design knowledge and the building design. To get to a dynamic support of design through feature models however, it is also necessary to understand how these models change, and which tools are required to make these changes possible.
For this purpose, we have made a case study of a concrete design from an architect's office and described the design process in terms of changing feature models. This was achieved by taking all the drawings made during the design, describing each drawing as a design state in a

feature model, and analysing the changes from design state to design state in terms of changes in the feature model. The analysis per drawing was based on the research work on generic representations (Achten 1997). Through this work we have established a classification of design actions that, to date, amount to eight classes of changes in the design process (Achten and van Leeuwen 1998; Achten and van Leeuwen 1999).
The classification is very useful when tools will be developed that support the designer. Usually, the propagation of changes in a design, while maintaining a consistent model is very hard, and, perhaps, even impossible. Understanding what exactly goes on during design actions can aid in this respect and also give more insight in design reasoning processes.

Feature view and model view

In our discussions on the envisioned VR-based design aid system (system I) we distinguish between two basic views of the design: the model view and the feature view. The model view shows the three-dimensional geometric design with additional representations for cost, structural stress, energy loss, etc. The model view is a representation with a high degree of verisimilitude. The feature view however, enables the designer to see and manipulate the underlying datastructure (feature model) of the design. The feature view option has the advantage that it can address more semantic properties of the design that are hard to represent in geometry. The information stored in the feature model is present in different degrees of abstraction. The designer may choose to manipulate those rather than the geometric representation (for example when changing the heat transfer quotient of a wall, changing the colour of a whole group of objects, or when some information about objects needs to be found).

Knowledge from education

The Design Systems group is quite involved in teaching in the Department of Building and Architecture. Historically, this has been basic CAAD training as well as design methodology and theory. In 1998, with the formulation of the VR-DIS programme, a more fundamental link between teaching and research was initiated. Parallel to the research effort, a Design Studio was initiated in which prototypes could be tested and used in ongoing design projects. The Design Studio features six Intergraph computers that can support desk-top Virtual Reality. From its inception, the Design Studio has proven to be of great value in understanding, in particular, the challenges of VR in design and the current difficulties in using it. Also, it is a very usable test platform for developed prototypes.
A second educational stream that is connected to research is two projects on distance learning and CAAD: the AVOCAAD project, completed in 1999, and its follow-up, AVOCAAD Multi. Both projects are initiated and co-ordinated in Brussels, with the Hogeschool voor Wetenschap en Kunst (WenK) and feature research partners in Europe. A third teaching/research project has been started by WenK and the Technical University Delft called {ACCOLADE}, which is a European start-up workshop for collaborative design. The work here has significance to the developments in system II mentioned above.

14.4 Results and ongoing work

By its very nature, the VR-DIS research programme relies on multidisciplinary research. People from Design Systems participate in many ongoing projects that are located in different groups and departments. For this purpose, the following list also mentions the locations of research. Successful collaboration has been achieved, in particular, with Building Physics and Computer Graphics.

14.4.1 Finished research projects

- 1996. Ph.D.: Bauke de Vries. "Communication in the Building Industry – A Strategy for Implementing Electronic Information Exchange." Building Information Technology.
- 1997. Ph.D. Henri Achten. "Generic Representations – An Approach for Modelling Procedural and Declarative Knowledge of Building Types in Architectural Design." Design Methods Group.
- 1999. Software: Ren Manager 1 and Ren Manager 2. Design Systems.
- 1998. Software: Joran Jessurun. WUPWalker routine. Design Systems.
- 1998. Software: Joran Jessurun. Feature Manager. Design Systems.
- 1999. Ph.D.: Richard Kelleners. "Constraints in Object Oriented Graphics." Computer Graphics.
- 1999. Ph.D.: Jos van Leeuwen. "Modelling Architectural Design Information by Features – An Approach to Dynamic Product Modelling for Application in Architectural Design." Building Information Technology / Design Systems.
- 1999. Ph.D.: Ellie de Groot. "Integrated Lighting System Assistant." VR-DIS / Building Physics.
- 1999. Software: DDDoolz. Design Systems.

14.4.2 Ongoing research projects

- Ph.D.: Marc Coomans. "Visualisation and Manipulation of Dynamic Data Structures in Virtual Reality." VR-DIS / Design Systems.
- Ph.D.: Shauna Mallory-Hill. "Workplace Environment Design Assistant." VR-DIS / Building Physics.
- Ph.D.: Maciej Orzechowski. "Measurements of User's Reactions and Behaviour in VR for any Building Environment." VR-DIS / Urban planning.
- Ph.D.: Amy Tan. "The Reliability and Validity of Interactive Virtual Reality Computer Experiments." VR-DIS / Urban Planning.
- Ph.D.: Nicole Segers. "Interactive Architectural Design Tools in Virtual Environments." VR-DIS Design Systems.
- Project: Brite Euram: "Refurbishment." Design Systems / Vastgoedbeheer
- Project: Building Management Simulation Centre. Design Systems / Calibre.
- Project: E3DAD (Easy 3D Architectural Design). Design Systems / Instituut voor Perceptie Onderzoek / Computer Graphics.
- Software: Joran Jessurun. REF Manager. Design Systems.

14.4.3 Summary of key projects and results

Many research projects yield applications for testing the work in practice. These can be conceptual mock-ups that mimic intended functionality, but they can also work as normal running software. Table 14.1 shows a list of products and the scientific methods that form the theoretical and scientific basis of the work. Products between "{ }" are in development. Names between "( )" indicate additional participating groups in the research.

TABLE 14.1. Products and methods in VR-DIS

Products	**Methods**
Feature manager	Feature based modelling. Flexible and extendible data information model for design.
{CBR system}	Generic representations. Analysis method for capturing design decisions established in representations. Retrieval of cases based on design drawings.
{Exspect simulation}	Message exchange model. Simulation of the information exchange process between the participants in a building project.
Feature view	Feature visualisation and manipulation in Virtual Reality.
DDDoolz	Face orientation method. Use the face of a voxel as a plane of reference for generating new voxels.
VIP (IPO)	Design support for collaborative design in the VIP augmented reality system.
Constraint solver/tester (W&I)	Geometric constraints. Constraint definition between 3D objects. Propagation and maintenance in a designerly fashion.
Blocks (W&I)	Implicit geometric relations. Relations defined in the design without explicitly stating them. Recognition and maintenance. Interpretation of various meanings during design actions.
ACAD -> 3DS -> WUPWalker	VR Cycle. Fast cyclic method of incorporating Virtual Reality in the design process to investigate influence of VR.
WEDA & ILSA	CBR, KBS. Case definition in the fields of lighting design and comfort in workplace and reasoning in new design situations.

14.4.4 DDDoolz

The first prototype of a truly 3D sketch tool in VR was developed initially by Bauke de Vries during a sabbatical leave at the ETH Zürich. DDDoolz was meant to demonstrate an approach in which sketching was as easy as point, click, and drag, without addressing any extra command structure through menu's or keys.

DDDoolz is a voxel system, meaning that the smallest element is a cube. The basic idea of DDDoolz is that any creation act starts from an existing voxel. New voxels can be created by clicking on the side of an existing voxel, and taking that side as the implicitly defined plane of reference, drag new voxels with a pointing device. Voxels can be rotated to achieve different orientations, moved and deleted.
The user interface has proven to be very simple and effective (see Figure 14.2). The system has been given to first-year students of architecture with an assignment to create a small exhibition pavilion. After a short while, student were able to work and design with DDDoolz. Since it is implemented in VR, the user can immediately walk through the design while still designing.

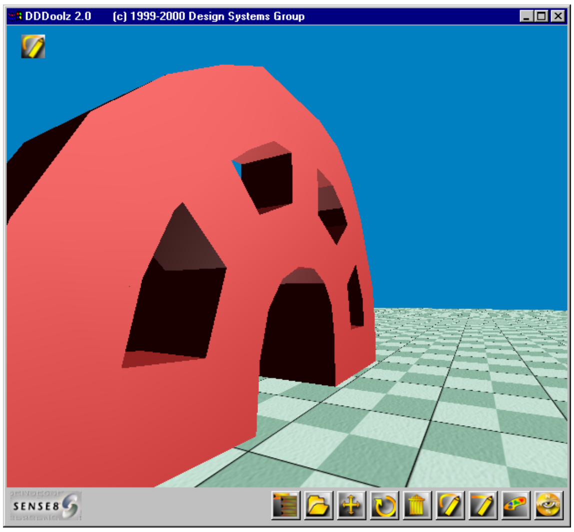

Figure 14.2: DDDoolz (version 2).

The software has also been used in an architect's office for evaluation purpose. The positive reaction and feedback on additional functionality has prompted the effort to find financing for the further development of the tool. Later additions to DDDoolz have added some aspects of gesture-based shape recognition and have restyled the user interface. In all cases, DDDoolz proved the validity of the concept of the minimal user interface and a simple and direct approach to design.

14.5 Conclusion

The Design Systems group has an active interest in design research focused on computational design support. The research and development work on design aid systems in the VR-DIS programme needs to have a foundation in an understanding of design. For these reasons, the Design Systems group has organised a number of activities in the field. These include: Design Research in the Netherlands (1995, 2000), Design Education in the Netherlands (1997), Design Futures (1999), Ontwerpend Leren – Leren Ontwerpen (2000), and together with Shauna Mallory-Hill a Case-Based Design workshop (1998) with Professor Mary Lou Maher as guest speaker. The group will organise and host the CAAD Futures 2001 conference in Eindhoven (Vries, van Leeuwen and Achten 2001). In a broader context, John Carp has organised the Supervisor (1998) symposium, and the Themawijken symposium (to be held may 2001), and has been involved as advisor in a historical overview of the SAR (Bosma et al 2000).

The work on Feature Based Modelling has provided a methodology for capturing design processes in a formalism that is understandable to a computer system. The formalism also provides a very detailed way to study design processes. Mechanisms can be defined that play a role in design processes. As a result, there will be a formalised description that can run on a computer, which provides one viable explanation of a design process. The question whether such a description holds for the actual cognitive processes of a designer must be left open here.

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