Virtual Reality in the Design Studio: the Eindhoven Perspective

Henri Achten, Walther Roelen, Jan-Thijs Boekholt, Arthur Turksma, Joran Jessurun

Since 1991 Virtual Reality has been used in student projects in the Building Information Technology group. It started as an experimental tool to assess the impact of VR technology in design, using the environment of the associated Calibre Institute. The technology was further developed in Calibre to become an important presentation tool for assessing design variants and final design solutions. However, it was only sporadically used in student projects.
A major shift occurred in 1997 with a number of student projects in which various computer technologies including VR were used in the whole of the design process. In 1998, the new Design Systems group started a design studio with the explicit aim to integrate VR in the whole design process. The teaching effort was combined with the research program that investigates VR as a design support environment. This has lead to increasing number of innovative student projects.
The paper describes the context and history of VR in Eindhoven and presents the current set-up of the studio. It discusses the impact of the technology on the design process and outlines pedagogical issues in the studio work.

Keywords*: Virtual Reality; Design studio; Student projects*

Historical context

The Calibre Institute was founded in 1988 by the Faculty of Architecture, Building and Planning of Eindhoven University of Technology. The main goal for this Institute was to perform research and education on the combination of computer science and architecture. At the time the Institute started its work, the only computer applications that could directly be used in the field of architecture, building and planning were Computer Aided Design (CAD) programs. These programs ran on main-frames and minis with graphical terminals attached. In combination with Abacus (an institute of the University of Strathclyde, Glasgow Scotland) where prof. Tom Maver lead the research, the Institute participated in the development of a set of CAAD-tools: VIM, BIBLE, and Viewer. The Institute in combination with the Building-Informatics group started courses in basic computer usage and the use of the CAAD-tools mentioned above.

Shortly after this first period the development of PC's and PC-based applications reached such a level that they also could be used for CAAD. From that time on 'standard' CAAD-applications like AutoCad and MicroStation were explored and used in education. These programs were first designed to facilitate 2D-drawing but over times more and more 3D features were built in. The development of CAAD-tools was stopped in the Institute and focus changed to the application and adaptation of commercially available CAAD-programs. Calibre also started research and did developments on many other applications that could be used in or adapted for architecture, building and planning. For instance programs for facility management, planning and cost-calculation were developed (Bouwplan, 1990). To investigate the possibilities and to facilitate the educational tasks of the group, Calibre also developed computer-aided-learning programs (CalInCAD early 1990'ies, Geberit bathroom program 1998, 1999).

Because the purpose of the Institute also was to bridge the gap between industry and university, most of the research and development was done in partnerships with or based on contracts with parties from the building-industry. Especially in the Netherlands the building-industry is very fragmented, many small companies participate in the design, development and construction of a building. To initiate and invest in research programs of the university was therefore difficult or impossible for these companies. Participating in a research-project of the Calibre Institute was much easier since it did not have the disadvantages of high financial and elaborate legal consequences of signing a contract with the university. The Institute could also deliver guarantees on the cost and quality level which a university would never do.

VR: First steps

The building-industry is one of the few industries that lack the possibility of using full-scale prototypes to evaluate and test their designs. Until then the only means to communicate designs to other partners in the process of building and to the customers and designers themselves, were sketches, drafts drawings, artist-impressions and small-scale mock-ups. CAAD and 3D-model based visualisations seemed to open possibilities to overcome at least part of this problem. A lot of effort was put into the research, development and adaptations of these programs to make them suitable for the use in our context. Filters and converters were written to facilitate the use and re-use of design related data, especially for visualisation purposes. At the same time simulation programs were developed to evaluate the technical aspects of buildings. Programs to calculate and predict constructional and acoustical aspects of buildings were created. Special effort was put into the development of programs that simulated the behaviour of light in and around buildings (Rayder and Dim: Dynamic Illumination Model). These programs could serve two purposes. First the prediction of illumination, luminance and colour helps to create buildings with better performance and higher comfort in respect to lighting. Secondly the data from lighting-simulations can be used to enhance the level of realism in visualisations.

Renderings of 3D-models proved to be intuitive and efficient tools for the evaluation of an architectural design. At first these rendering were presented as still images, later when the performance of computer systems allowed the rendering of multiple images in a short time animations were used. The animation mostly consisted of walk-throughs and fly-overs. Since the images and animations only could show what was previously chosen to be visualised the recipient was not able to interact with the design. The user could only perform the role of a spectator. Especially for the designer himself but also for the other users of architectural visualisations this lack of interactivity was a major disadvantage.

When in the early nineties Virtual Reality Systems became commercially available Calibre did not hesitate to invest in VR hard- and software. Virtual Reality held the promise to develop into a tool for intuitive, interactive and realistic evaluation of (non-) existing three-dimensional environments. In fact Calibre bought one of the first systems that were produced by Division. Division now is world-wide the biggest company on VR-software. Using this transputer-based system the possibilities of VR in architectural design were investigated. The poor performance of such systems combined with the relative low quality of the peripherals made them unusable for direct application in the architectural practice. But the system gave Calibre the opportunity to investigate future possibilities, to participate in the development of the next generation systems and to gain experience and acceptance in the field. As expected both performance and quality of VR hard- and software increased enormously over the years.

Calibre initiated and participated in many research-projects on the application of visualisation and simulation in general and more specific in Virtual

Reality.

Ideas and initiatives of G.T.A. Smeltzer, the director of the Calibre Institute at that time, combined with the research and graduation projects of W.A.H. Roelen and J.M.M. Mantelers made Calibre one of the leading names in the field. Tools for the evaluation of architectural designs, for constructional- and lighting-simulation were developed. These tools were tested in the architectural and building practice and also used for educational purposes.

Towards a mature presentation tool

Based on the projects and research mentioned above Calibre as an Institute became a centre that rendered services based on Virtual Reality. These services in many cases consisted of the use of VR as an intuitive and interactive presentation tool. At first they were restricted to presentations of definitive designs, which were used to communicate the designs to customers, project managers and other parties with no real architectural background. But later it was used more and more in all stages of the design process, for communication between partners in the design and building process and for communication, evaluation and reflection of the designer himself. The addition of simulation tools for the real-time evaluation of technical, ergonomic, esthetical, constructional, logistic and other functional qualities of the design contributed heavily to the efficiency and acceptance of VR-based design aid tools. The promises and possibilities held by this concept gave birth to a Faculty-wide research program called VR-DIS (Virtual Reality Design Information Systems). One of the main goals of this research program was and still is the integration, communication, and automation of knowledge and experience between all building and architecture related disciplines. This period is characterised by a main focus on development of VR rather than incorporating it in teaching.

The big shift: firm and education

While the technique and applications matured, the research aspects, especially in contract-research projects, became less important. The level of investments necessary to maintain the "state-of-art' status of the facilities however stayed very high. Among other reasons this gave birth to the initiative to stop the activities of Calibre as an Institute and to the foundation of the company Calibre. The company still facilitates the administration, management and acquisition of the contract-research of the Design Systems group. But for projects with no research aspects it acts as and is treated as a normal commercial company. The company now renders services on simulation and visualisation for all branches of the industry. The experience and knowledge appeared to be applicable in many areas, which opened up a much bigger market for the company. Also, gathering experience in other fields helped the further development of tools for the building industry. The abbreviation VR-DIS was also adopted by the Calibre company but with a slightly different interpretation: Virtual Reality based Distributed Interactive Simulation. The use of the same 'name' in both the faculty and the company shows the relation that still exists.

"VR-DIS" can be used in two contexts. First it has been made possible to share the virtual (visual) simulation over the network. We adapt, exploit and investigate the possibilities of this feature in many applications. For instance; it is used to share a presentation of an architectural design with someone over the network. Quick collaborative evaluations can be made this way saving time and travel-costs.

Secondly we use the term when the visual simulation and the simulation of physical behaviour do not run on the same machine. For instance the lighting simulation algorithm (Rayder) can run on a Cray where the visual simulation driven by the output of the Cray run 'simultaneously' on an Onyx.

A number of graduation projects started to utilise the Virtual Reality equipment of the Calibre Institute. Notable projects were:

- Marc van Grootel. After a stage at the ETH Zürich, Marc showed a VR model of the library design by Koolhaas for Paris (Bibliotheque de France). Interesting architectural features in the model were the analytical approach, dynamic behaviour of the constitutive elements of the design, and dynamic slicing which gave a good impression of the spatial development of the building.

- Marc Coomans. For his post-graduate course, Marc made the VIDE program, which dynamically coupled AutoCAD with a VR environment, programmed in World Tool Kit. Elements designed in AutoCAD were shown in VR, and vice versa. The program demonstrated the use of VR and the potential of mixed representations (plan and immersion).
- Max Brünner. Max used VR to develop his housing design for an urban infill project in Eindhoven from the very start. He developed a complex spatial scheme in a restrictive site and made his final presentation completely in VR. An innovative approach was the use of radiosity texture maps to increase the realism in the VR presentation.
- Rob Robbers. Rob developed an office building at the seashore based on a competition by Boele en van Eesteren for the office over 100 years. He explored interactivity both in the design process, the building design itself, and the relation user-building. Reversed kinematics was used to establish the shape of the building.
- Arthur Turskma. Arthur made a virtual museum, based on Le Corbusier's Musee Illimitee, and explored a number of ways to combine multi-media, VR, navigation modes, and presentations modes to see where the potential use of VR in architectural and virtual design could lie.

These projects gave an impulse to the use of the VR equipment in the educational context, and it prompted the Building Information group to study on a more consistent application of VR in the design work. This has lead to the Design Studio.

Current status

In the period that the Calibre Institute became a business, a merger process was going on with the Design Methods group and the Building Information Technology group. The new name of the group has become "Design Systems" which shows the focus on both information technology and design. The previously mentioned VR-DIS programme became the research foundation of the group. In the Design Systems group, DIS stands for "Design Information System" at the moment. The aim is to investigate how VR can facilitate design support. The core approach lies in a Feature framework developed in the group for the domain of architectural design (van Leeuwen 1999, van Leeuwen and Wagter 1998). The framework allows flexible and extendible definition of design information, thus providing the essential basis for design support (Achten and van Leeuwen 1999). A Feature tool and API have been developed, as well as a design prototype that instantiates a Feature Model and with real-time geometric constraint solving (Kelleners 1999, de Vries and Jessurun 1998).

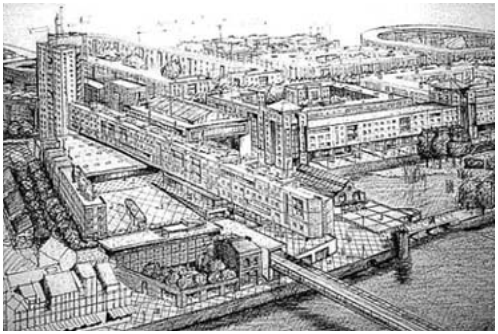
The VR-DIS programme identified education as a complementary activity that could support the understanding of VR in the design process. Also, it would help in disseminating the results of the research work in architectural education. For this purpose, and the boost from the student projects mentioned above, the Design Studio was started. In the Design Studio, we have six desktop VR machines that enable students to use VR from the very start of the design process. This is facilitated in the so-called VR-cycle that will switch from AutoCAD via 3DStudio Viz to WorldUP within 10-15 seconds (Achten et al. 1999).

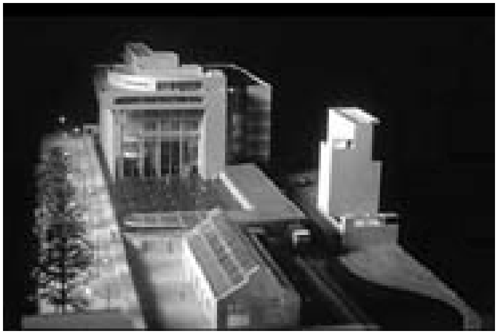
Synchronous and asynchronous (distributed) collaborative design is also being studied in the Design Studio, in which VR plays a role. In this way, we are able to assess the impact of VR in the design process in many ways and to confront students with innovations in architectural design. Through lectures and demonstrations in the Calibre presentation room student become acquainted with work in architectural practice and this establishes a fruitful exchange of ideas.

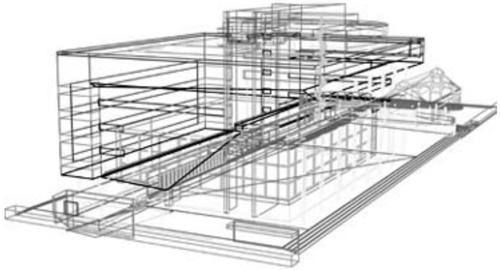
Challenges of the future

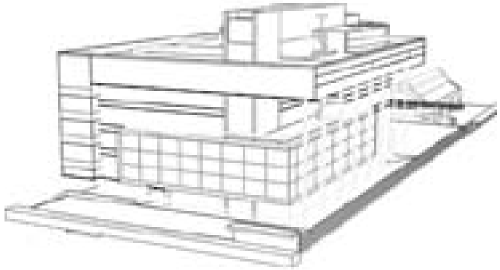
Virtual Reality has proven to be an enabling technology in architectural design. Established VR practice comprises:

- *Visualisation of realised and built designs.* The impact of an immersed "encounter" with a design is powerful and aids in assessing the spatial quality and relations in a design that one has never seen before nor visited. People can easier understand the consequences of a design when being confronted with a VR model, and they become faster familiar with an unknown building rather than through other representations. A seminal example is the Taj Mahal project (1994), as well as the Schiphol project (1994), autobus project (1999), Wiel Aretz Rotterdam project (1996), and the Vienna subway project (1997).
- *Predefined interaction with environment and objects*. Environments with predefined dynamic behaviour can show for example the working of equipment or the situation in a street. In this way, instruction and test of new situations is possible, thus avoiding the cost of









Images of the same architectural design using different media (continued overleaf).

Figure 1 (right top). Sketch of the new Maastricht library: Centre Ceramique by Jo Coenen Arch.

Figure 2 (right bottom). Scale model of the new Maastrict library: Centre Ceramique by Jo Coenen Arch.

Figure 3 (far right top). Wireframe of the new Maastrict library: Centre Ceramique by Jo Coenen Arch.

Figure 4 (far right bottom). Hidden lines of the new Maastrict library: Centre Ceramique by Jo Coenen Arch.

expensive mock-ups. Examples are the Philips Medical Systems projects (1996).

- *Comparison of design alternatives.* Differences in design alternatives can be shown quite dramatically in Virtual Reality by switching between them. In particular spatial and material (texture) consequences can be shown easily in this way. Examples are the Ericsson Headquarters project (1994/1995), the Rabobank interior project (1996), and Eindhoven campus project (1996).
- *Evaluation of visual aspects of a design*. The assessment of spatial organisation of a design, the internal routing, lines of vision, and ease of orientation are very well supported in Virtual Reality systems today. Examples are graduation projects of Max Brunner (1998), Rob Robbers (1997), Frank Janssen (1999), and the social housing project (1997).
- *Autonomous behaviour*. Objects in a VR-model have behaviour and are linked to each other in ways that mimic natural behaviour and relations: doors are hinged, objects are subject to gravity, stairs can be used to reach a higher level in a building model, etc. These aspects, though sometimes trivial, actually enhance the effect of immersion and cognitive grasping of the model. They are implemented in the majority of VR projects.
- *Simulation*. Lighting simulation not only enhances the rendered quality of an image, and brings forward the architectural qualities of a design, it can also support a more detailed understanding of a lighting design itself. The Raider algorithm has been implemented on a Cray computer, allowing real-time radiosity (presented on Super Computing '98 at Orlando). Non-visible aspects such as acoustics, construction, and logistics can also be simulated and thus provide a different way of studying these aspects. Examples are the Puerto Rico project (1999), and the Building Simulation Management Centre project (ongoing).

In the past decade we have seen the technology mature into a stable platform that has been used for the purposes described above. Yet it does not seem that the full potential and implications of Virtual Reality

Images of the same architectural design using different media (continued from overleaf).

Figure 5 (top). VR-view of the new Maastrict library: Centre Ceramique by Jo Coenen Arch.

Figure 6 (middle). VR-view of the new Maastrict library: Centre Ceramique by Jo Coenen Arch.

Figure 7 (bottom). Foto of the new Maastrict library: Centre Ceramique by Jo Coenen Arch.

have been realised. To name a few:

- *Multi-user presence in a virtual environment*. Most VR systems facilitate viewing for one person with a head-mounted display or more persons viewing a projection screen. This is different however, to having other people present inside the model, represented as avatars. Many less computation-intensive virtual environments (such as MUDs, MOOs, games, and net-meeting software) feature this option, which gives a tremendous boost to their usefulness. A particular project running now at Calibre is the Maastricht virtual mockup of the complete city of Maastricht (50 km^2).
- *Real-time dynamics*. When a Virtual Reality system get information from the outside world, or when a simulation is running, then real-time data can be shown in the virtual environment. Real-time dynamics can visualise concurrent processes that otherwise are difficult to grasp. Examples are the influence of a building design on wind conditions, change of user behaviour, traffic patterns, etc.
- *Dataspaces*. Virtual Reality technology is seen as a crucially important aspect in cyberspace. In all cases, representing such abstract sets of data in a three dimensional immersive environment is generally seen as helpful for understanding them better.
- *Interface technology*. The interface still is very much present between the user and the Virtual Reality system. Developments in this aspect concern three aspects: display, hardware, and software. Stereoscopic rendering makes a powerful difference as opposed to mono (desktop) rendering but HMD's are clumsy, tiresome to wear, and offer low resolution. As the precision and performance of hardware increases, software still has to interpret the input and provide an appropriate metaphor. Natural language processing, a more accurate gestural approach, multi-modal input, awareness of user intentions (Wijk and de Vries 1999), and higher precision are required to make the interface less obtrusive.
- *Design aid tools in VR*. Not only the option to shift the occasional wall in an almost finished design would facilitate the user in a VR system, but also concrete design support from the very start. Architectural design is spatial by nature, and Virtual Reality should therefore be the natural medium for developing it. Design aid tools however, are at the very beginning of conceptualisation and development. An important challenge lies in translating the limited physical scope of the designer (range and precision of movements) to the large elements of an architectural design (spaces, walls, structural cores, urban areas). A pioneering example of such an application is Marc Coomans' VIDE system (1995/1996).
- *Research into basic assumptions*. The early development of Virtual Reality, as was the case with early CAAD, relies for a great deal on unspoken beliefs: it better supports our cognitive capacities, implies an easier user interface, facilitates making mental maps of an environment, etc. It is necessary to establish a sound research framework and critically address these assumptions.
- *Assimilation of various techniques*. As the power of computer systems increases, Virtual Reality technology will be incorporated into different applications. CAAD packages will have a VR option for walkthroughs of the design in its various stages, operating systems will trade the desktop metaphor for a spatial one, and the Internet and data browsing and mining will become spatial. The other way around however, will also occur. Other techniques such as data exploration

and office applications will become integrated with “classic” VR.

Conclusion

The history of VR from the perspective of Eindhoven has shown rapid development of this technology from a tentative start to a sound and established technique. Many pathways to the future are open for exploration and defining the potential of this technique. The most notable challenge lies in finding a new paradigm for co-ordinating technology, interface, and user.

As VR technology becomes more ubiquitous, architectural design will open up for discourse among participants who are not all versed in traditional design representations. More people than now will be able to understand in an earlier phase consequences and implications of a design proposal. For this purpose, it is necessary to develop new representations that will convey the tentative character of the design. From our experience in the design studio, this is not at all a trivial matter.

Design tools in a VR environment will become more intuitive to use. Design will exhibit autonomous and simulated behaviour that will enhance understanding. Complex design tasks will be easier to control and grasp providing more freedom to tackle the basic issues. New ways of information sharing in co-operative design will become available.

Acknowledgements

A decade of work in two closely related groups encompasses a large number of people who have contributed to the presented work above. The setting of the studio and work in the Calibre Institute and business have always taken place in an informal environment which featured a lot of interaction between all members of the groups. From the Calibre Institute and company, special mention should go to Walther Roelen, Jo Mantelers, and Geert Smeltzer. From the Design Systems group special mention should go to Sjoerd Buma, Jan-Thijs Boekholt, Joran Jessurun, Arthur Turksma, and Henri Achten. The Design Studio was made possible through funding of the Department of Architecture, Building and Planning of the Eindhoven University of Technology.

References

Achten, H.H. and Turksma, A. (1999). Virtual Reality in Early Design: the Design Studio Experiences. Nys, K. and Provoost, T. and Verbeke, J. and Verleye, J. (eds.) 1999, AVOCAAD Second International Conference, p. 327-335.

Achten, H.H. and van Leeuwen, J.P. van (1999). Feature-Based High Level Design Tools: A Classification. Augenbroe, G. and Eastman, C. (eds.) Computers in Building. Proceedings of the 8th International Conference on Computer Aided Architectural Design Futures.

Kelleners, R.H.M.C. (1999). Constraints in Object-Oriented Computer Graphics. Ph.D. thesis. Eindhoven University of Technology.

Leeuwen, J.P. van and H. Wagter (1998). A Features Framework for Architectural Information, dynamic models for design. J.S. Gero and F. Sudweeks (eds). Proceedings of Artificial Intelligence in Design ’98, Lisbon, Portugal, 20-23 July 1998.

Leeuwen, J.P. van (1999). Modelling Architectural Design by Features. Ph.D. thesis. Eindhoven University of Technology, Department of Architecture, Building and Planning, Bouwstenen 54.

Smeltzer, G. T. A. and Roelen, W. A. H. (1995). Virtual Reality in

Architectural Design and Real Estate Simulation. Proceedings of Virtual

Reality World '95, IDG Conferences and Seminars, pp. 99-112.

Vries, B. de. and Jessurun, A.J. (1998). An Experimental Design System for the Very Early Design Stage. Timmermans, H.J.P. (ed.) Proceedings of the 4th Conference on Design and Decision Support Systems in Architecture and Urban Planning, Maastricht.

Wijk, J. van and Vries, B. de (1999). Towards an Understanding 3D VR Architectural Design System. Nijholt, A. and Donk, O. and Dijk, B. van (eds.) 1999, Interactions in Virtual Worlds: Proceedings Twente Workshop on Language Technology 15, p. 219-224.

Notes

i. Architectural Walk-Through Coupled with a Parallel Lighting Simulation http://www.startap.net/igrid/neth-usa.html

i. Calibre BV Web site, http://calibre.ds.arch.tue.nl/

ii. Design Systems Web site, http://www.ds.arch.tue.nl/

iii. Marc Coomans' VIDE information, http://www.ds.arch.tue.nl/general/staff/marc/vide.stm

Henri Achten[(1)], Walther Roelen[(2)], Jan-Thijs Boekholt[(1)], Arthur Turksma[(1)], Joran Jessurun[(1)]
[(1)] Design Systems Group
Eindhoven University of Technology
Faculty of Architecture, Building and Planning
[(2)] Calibre BV
Eindhoven University of Technology
h.h.achten@bwk.tue.nl