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Boosting up Architectural Design Education with Virtual Reality

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Abstract

One of the challenging tasks is to bridge the gaps among different engineering areas. Nowadays VR tools are commonly used in mechanical engineering but are not frequently used by architects. We present a description of a VR center and its application to architectural education. The main purpose of this paper is to share our first experience with the application of the system in education. We want to show the system requirements, advantages and disadvantages, and our experience with its implementation to education. The system is based on a synchronized dual PC and ceiling-mounted passive stereoscopic projection. SpaceBall is used to interact with the 3D objects and passive polarized glasses for viewing. Our results show that VR significantly helps students to understand principles of architectural design as well as to professors to explore the student's projects and detect hidden flaws. Co-exploration of virtual buildings by groups of students leaded by a professor significantly helps to understand the architectural design and improves the knowledge sharing.

Categories and Subject Descriptors (according to ACM CCS): K.3.1 [COMPUTERS AND EDUCATION]: Computer Uses in Education

1. Introduction

We live in the age of an apparent paradigm shift in architecture. For hundreds of years the classical way of architectural design started on a paper and finished with a final prototype that was sculpted by hand. The enormous boom of Computer Graphics (CG) applications and, in the past decade, CG hardware, made possible the usage of advanced techniques by the "mortal" users on their desktops. Design by prototyping, using CG to display models, making complete models by means of computer, functional testing, prototyping, are just few things that are nowadays the standard and standardized procedures in mechanical engineering.

Industrial architectural design is barely so advanced and the usage of Computer Graphics is mostly reduced to a photorealistic animation or image that is generated at the end and demonstrated to potential clients. Limitations of these approaches are obvious. Many architectural offices are still based on the 2D design (so called digital desk) simply because it is considered faster and easier way to draw the complete documentation for building permit issue or construction. And this is still the strongest part of the architectural market. The complete information that resides in the computer's memory is not explored adequately.

What is the impact the designed space has on visitors? How does the observer perceive the proposed areas? Is the shape proposal correctly designed in all details? Is this type of furniture suitable or another one should replace it? Is this type of window allowed? What will be the views from different angles and positions? All these, for architecture basic questions, cannot be easily answered by the use of classical approaches. Very tedious process of extractions from the CAD 3D model must be done to get visually credible output.

The 3D exploration and higher interactivity is needed and VR techniques seem to be the most appropriate for solving these cases and answering the questions described above. A review of the models and modeling techniques used by architects can be found in [MSM05, PJ03]. The latter shows how the collaboration in learning and teaching in VR helps to

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students as well as professionals in the early stages of architectural design. A key factor that helped to improve learning was the collaborative design experience. Students collaborate using VR devices in creating and building architectural virtual buildings. They have seen how students were able to collaborate and efficiently manipulate 3D objects.

Kalisperis et al., [KOM*02] mentioned the need of more applications of VR in architecture. The main contribution they've pointed out is that learning architectural design can be accelerated by VR namely at the beginning of their professional career. Students are able to participate that is an important shift from only observing the 3D buildings.

CALVIN [JL96] is an immersive VR design environment that has been applied to many applications including architectural education. The experience of the participating individuals shows that VR is a valuable tool not only for architect but also for all contributing public that can, without a particular experience, contribute to the architectural design.

A comprehensive book of Bertol [Ber04] discusses various aspects of VR and its application to architecture. Even though the book is aimed to professionals she mentions a wide range VR applications walkthroughs, simulations, and evaluations to reconstructions and networked environments and from the educational aspects she explores the potential impact of digital architecture on the built environment of the future.

One of the principal aims of architects is to have all the information visually disposed all the time during the designing process. Architects want to see their products before they are actually constructed; they want to see them in an interactive way; they would like to walk through them, etc. Simply, they want to know whether the proposal is correct or modify it repeatedly until the desired shape/form is reached. This kind of visualization is not only important for designers, but is useful also for clients, who can easily communicate with architects and might change some undesired things before they are actually constructed. All of the above-described aspects are native to VR applications.

2. Problem Motivation

2.1. Virtual Building

A new general concept of Building Information/Industry Modeling (BIM) (see Figure 1) was recently introduced [BIM]. Different products use this concept under different names, for example ArchiCAD [Arc] coins the term Virtual Building (VB). The same product uses the IFC format (Industry Foundation Classes) [IFC] for data exchange. BIM is a working, exact, and fully 3D model description of a building and it is connected with a database of additional semantic information. This information is used to generate the complete project documentation that has two important parts - technical drawings, used for the building construction, and visual documentation, used by architects. Important applications of the BIM are facility management [FM], building lifecycle planning, city growth planning, etc.

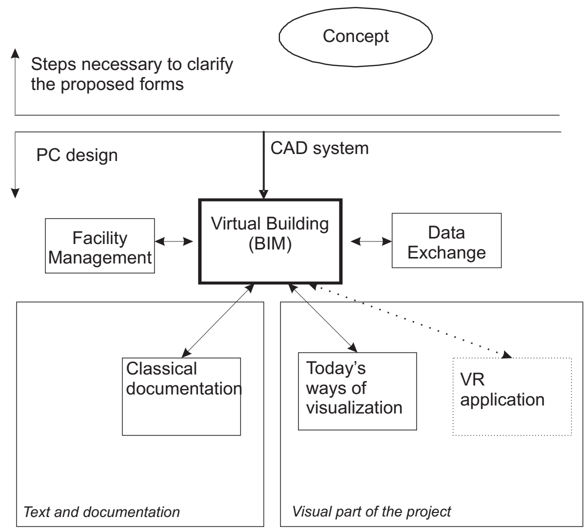

Figure 1: *Project design and the role of VR*

The concept of VB is a merge of different areas and that is probably why it is not used as it could be. It involves a collaboration of many different engineering areas and there is also a strong urge to merge different, already standardized, techniques and approaches.

2.2. The Role of VR

As mentioned above, the classical architectural output can have a form of technical drawing, sketch written by hand, photorealistic outputs (static or dynamic), or a physical model. Nowadays, it is impossible to imagine a work of an architect without the use of CG. On the other hand, the used techniques are really insufficient namely because of the lack of interaction.

In these days VR applications are used more and more frequently. The pure image is not sufficient for an architect and their needs are growing. The most important requirement is an unlimited possibility of the object exploration in real time with high levels of details. The list of requirements can be divided into different areas and includes, but is not limited, to:

- Real-time manipulation with an object and its exploration from all viewpoints.
- Geometrical precision and credibility.
- High level of detail.
- Exactness of appearance - physical, or physically based model of illumination, shadows, diffuse-diffuse inter reflections, mirroring, general BRDFs.

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- 3D displaying.
- Fast and immediate interaction and modeling (dynamic design).
- Interoperability and compatibility among a great variety of CAD systems.
- Atelier presentation - possibility to walk through the 3D model together with collaborators, discuss the product, highlight problems, etc.

3. VR Center

The main aim of our VR center is to provide teaching VR applied to architecture and civil engineering. In this way we prepare our students to deal with the needs that these days are bringing. Students can use the center to see their products modeled by means of standard architectural tools such as CAD/AEC systems or 3D modelers. Models obtained in this way are transferred into data native to the VR system and explored interactively. The schema of the VR center is depicted in Figure 2.

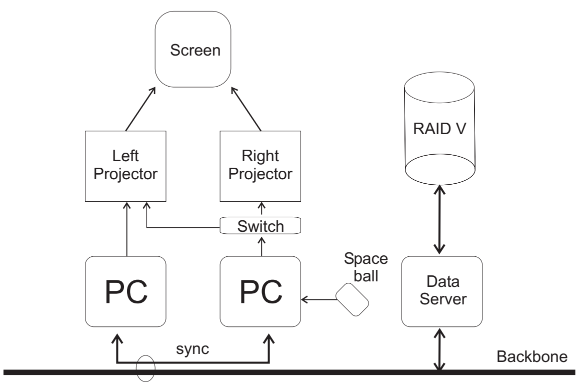

Figure 2: *The Schema of the VR Center*

3.1. Hardware

System is based on two Windows-based PCs each equipped with 2 GB of operating memory and NVIDIA GeForce 6800 Ultra graphics card. The PCs generate images for different eyes and they are synchronized over LAN. No GenLock is actually used. The SpaceBall 5000 is a specialized input device that provides efficient interaction with the VR model using six degrees of freedom. The output is generated for a passive front stereoscopic projection using two data projectors with 2500 ANSI lm light power. Both are assembled on the ceiling and the projecting plane AVM 3D is located in front on the wall. The reflected image has left and right information coded in the polarized light so classical stereoscopic polarized glasses is necessary to get the full immersion.

System is also able to work in a single-PC mode, where just one PC generates the stereo pair of images. In this way VRML [VRM] models can be displayed. A special electronic switch ATEN VS291 provides this function. This hardware device allows data projector input switching between the first output of the second PC and the second output of the first PC.

Architectural data is usually huge so an additional data server equipped with a RAID V is used. Several photographs of our VR center are shown in Figure 3 and its schema is displayed in Figure 2.

Figure 3: *Hardware implementation. From top to down - projectors, dual PCs controlling the projection, projecting screen and the classroom*

3.2. Software

The standard displaying software for such kind of applications is based on VEGA Prime from the MultiGen-Paradigm [MP]. This system uses OpenFlight format for data exchange. We also use the OKINO NuGraph for data conversion among different systems.

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4. Education

The task we are trying to solve is to increase the overall knowledge of VR systems and their usage among architects. The actual and future applications of VR in architecture and civil engineering are in the following areas:

- territorial planning,
- urbanism,
- design of interiors and exteriors,
- reconstruction of historical buildings.

These areas are directly related to the applications of VR in education and we apply the VR directly in the subjects above mentioned.

Figures 4 and 5 show an example of a 3D model generated by ArchiCAD that was then converted to OpenFlight format and displayed in VR using the VEGA system. Apparently the photorealistic output has all shadows, soft shadowing on the walls, reflection mapping, correct illumination etc. Majority of these effects are missing in the VR scene that is the price we pay for interactivity.

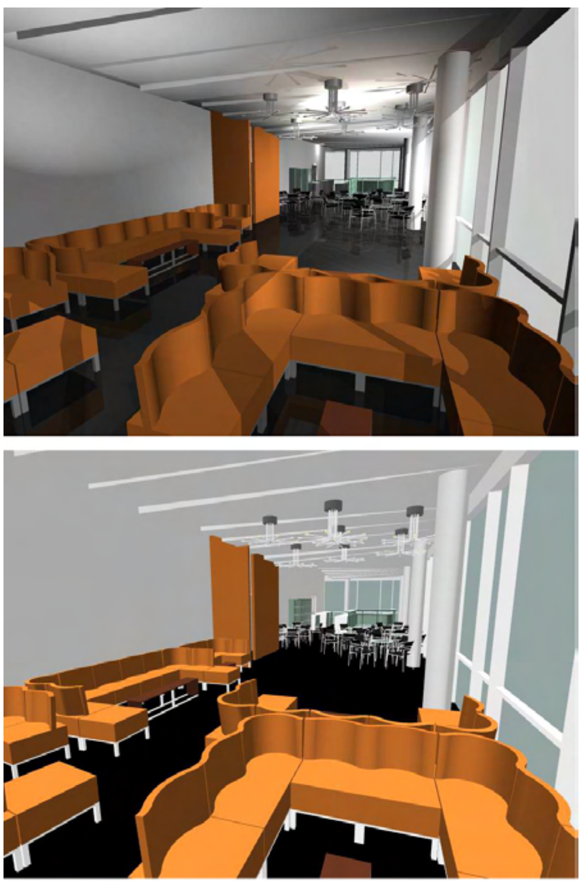

Figure 4: *Virtual scene created by our students. The upper image shows photorealistic output, the lower the VR output*

4.1. Students

Actually more than 20 students used the system. The level varies from undergraduate to graduate and the subjects that were tough are: virtual reality for architects and advanced virtual reality. The basic requisites include knowledge of 3D design in the classical way and the basic interaction in 3D.

The most important benefits for students are the new possibilities VR is bringing and the fact that students understand that this technology exists and it is possible to use it. They are prepared to face this technology in reality and will not be surprised with it.

Another, and much more important advantage, is the educative and training function of the VR technology. VR helps significantly to think in 3D. Student can see directly in 3D and this provides a good feedback for the future planning and actions a student can take. Students are able to detect faster their mistakes in VR, the stereoscopic perception is much stronger and students are consequently able to learn faster from their errors.

One of the most important benefits is the model properties parameterization. Once located inside the virtual environment, by simple selection a type of objects can be changed. For example texture of the floor, positioning of the furniture, type of table, etc. There is no need to re-render the model, all these changes are done in real-time and interactively. This helps to the orientation in the 3D scene and to future design as well.

4.2. Teachers

Application of VR in architecture brings also a qualitatively new experience also for professors. A student's project can be explored from all sides and with all details. Professor can see all details and, together with student, can detect and discuss design mistakes. Something that is difficult to do by classical desktop design, for example to sit down in the kitchen and see all the possible views, is done in VR easily.

Visual design exploration using VR environment is very effective as in VR all the design imperfections and flaws are made apparent just from scratch. The scene is completely explored and no errors can be hidden.

5. Problems and Future Work

5.1. Problems

VR in architecture is a growing area so there are a lot of problems as well. One of the principal technical problems is the conversion from formats suitable for the concept of Virtual Building to data suitable for VR. The IFC format is intended for semantic and 3D data and does not carry such information as a level of detail, potential visibility sets, etc. The roughly transformed data is huge and it is frequently difficult to process and display. The problem is that the huge

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data is the standard data architecture uses. Some concept of adaptive conversion is required and we are reaching limits of the current software technology here. We are limited to small and medium-size project simply because of the lack of suitable conversion tools that would allow us to display scenes we model in real time.

Another future problem is related to the level of today's computer graphics. The software is highly dependent on the fixed-pipeline OpenGL architecture and does not use any of the new advances of the GPU functionalities. There are no bump-maps, no pixel-level shaders, no shadows, etc. It seems to be just a question of time, but as can be seen on the Figures 4 and 5, the visual difference between the radiosity-based and Phong's illumination-based image is critical. The need of photorealism is not just a question of taste, as in videogames. In architecture the location of shadows, position of Sun in the morning and in the afternoon, mutual shadowing of objects, diffuse-diffuse interreflections (color bleeding), and all these aspects proper to Monte-Carlo illumination methods, are critical. This determines VR in architecture for manipulation with the shape of the objects, even though some advanced methods could be possible and also necessary.

One of the most important problems is the price of the VR devices. They are unquestionably attainable only to groups of architects, to universities, research centers, etc. That is why we see the evangelization role of our educational institution as crucial.

5.2. Opened Possibilities

We expect bridging the gaps among different areas of civil engineering, namely application of VR techniques together with GIS and other information systems. One of our research projects is enriching the static and passive VR models by semantic data, merging the parametric space of VR models by standards, rules, etc.

Another important opened door is the vivification of the passive virtual worlds by dynamics. Door should open, escalators and elevators should move etc. This will give full functional impression of the virtual building and this experience will be probably more important than the passive shape and form of the project. Nowadays, at a very low level, all these things can be done by VRML. There are some higher level SDKs (for example VEGA) but they are general-purpose tools and their price is also very elevated.

The quest for realism was already mentioned. The CG-native questions, such as position of shadows, intensity of the light reflected from a wall, etc. are crucial in architecture.

6. Results and Conclusions

The principal contribution of our paper is to show that VR can be applied to architecture education and helps to students increase the speed and insight of learning. We have described our system and advantages that it brings to the application of VR to education. Several problems were highlighted and the possible future work was discussed as well.

We believe that VR is a highly suitable tool that can significantly improve 3D perception of architectural models. Students understand faster modeling and design and can focus on the important problems.

We also think that architecture is a perfect application area for VR, where many future problems can be directly applied. Computer Graphics algorithms, such as global illumination, or advanced shading, can be implemented with their full potential. All the possibilities of hardware accelerators used namely in videogames, such as bump-mapping, pixel shaders, occlusion culling, etc. can be used in VR architectural applications as well.

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Figure 5: *Virtual city hall created by students. Upper images show the virtual object displayed on the screen, lower show the anaglyph and the rendered object*

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