Physical Simulation in a VR Tool for Urban Design

Frieder Schubert and Philipp Lurz
University of Stuttgart

Constantin Boytscheff, Bernd Jödicke,
Martin Merkler and Jens Wiesner
University of Applied Sciences, Konstanz

Abstract

Physical influences on a city, such as noise, light, air flow, and solar energy quantities, can already be simulated on computers; however, these simulations are usually not embedded into the urban planning process. Regarding a broad field of these influences and their correlations will improve the quality of the design. The use of simulations in the sketching stage provides the possibility of reacting accordingly for the urban planner, which is essential for sustainable design.

This paper describes the development of a virtual reality tool for the early urban design process, in which we realized a network connection between a software package calculating noise propagation in urban spaces and a virtual reality design environment. In this dynamic VR design tool, it is possible to experiment with simple geometric forms and objects (these objects can be added to constructions, removed, and transformed). Interactively, with each action of the planner, simulations are generated and visualized in the VR environment in real-time.

The last part of the paper describes our concept, how this VR design tool should be integrated in the study of urban planning, and how we want the students to get a sense for the impact of their design on physical phenomena in an urban scale.

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1 Concept

Next to esthetics, there are many aspects which have to be considered in architectural and urban planning. Planning becomes a very complex task and requires a broad knowledge in different scientific disciplines. The quality of the solutions resulting from the planning process increases with the number of criteria that are considered. But, even a well experienced designer gets to the limit of his ability by the number of aspects, their variability, and correlation that have to be regarded.

Computers are able to process a large amount of information through predefined algorithms in order to reduce the information to results that can be handled. Physical phenomena like the propagation of noise in urban spaces, air pollution, air flow, areas of light and shadow, and daylight and solar energy quantities can be simulated with the help of computers in that manner.

It is hard to foresee e.g. the distribution of noise in urban spaces. Architects and urban planners usually do not have extensive experiences and knowledge of the correlation between their design and the consequences for the spatial propagation of sound in urban spaces. Noise simulation software is able to improve this situation and can assist planners. In the context of this project, we decided to simulate the noise propagation in urban spaces with the aid of a special software package.

Usually just specialists have the know how that is necessary for the application of simulation software. These programs fit their particular needs, and they are almost the only ones using simulation software in a professional way. The application of simulation software is too sophisticated for the usual needs of architects and urban planners. That way, planning aspects which have to be simulated are not taken into consideration in the early design process or just at a later date when the boundary conditions are already defined.

In order to integrate computer simulation into the design process, it is necessary to simplify their application and to make the results and correlations among different aspects visible and understandable for architects and urban planners—especially when they are not observable without any simulation technology. The result of a simulation process is much easier to understand if it is visualized. By the simulation of physical phenomena in urban spaces, it is reasonable to treat them spatially in simulation and visualization. A suitable medium for 3D visualization is Virtual Reality (VR). VR is already established for scientific data visualization in disciplines like civil engineering and medicine technology. In architecture and urban planning, VR is only used occasionally and almost never serves just as an immersive presentation tool for CAD-models. But VR is also appropriate as a design tool. In distinction from the representation on paper or on screen, which is limited to two dimensional projections, VR features many benefits known from physical model making.

A significant advantage of VR in comparison to physical modeling is the ability to integrate design relevant information like simulation results within the early design process. This can not be realized with conventional models. This integration can be achieved by connecting the simulation and the VR environment, so that by each change of design parameters, actual simulation results are provided in real-time.

We suppose that in consideration of the technological development current CAD-workstations will be at least partially displaced by Augmented Reality and VR in architecture and urban planning within several years. This is not only true for those planning phases in which CAD is already used, but also for the early design process.

In spite of several already realized innovative VR-projects, the establishment of VR in architectural teaching and profession could not yet be achieved. But VR systems became simplified and significantly cheaper within years, which enables an easier application in teaching and practice.

Programs that are able to provide comprehensible and evaluable information on ecological questions are appropriate to assist teaching. They open up the possibility of integrating ecological aspects into the design process, which may affect the design itself. Therefore, the programs should fit the needs and abilities of designers and facilitate their practice. Designers should be able—similar to sketching and physical modeling—to create several alternative design variations quick and easily.

“r.Vipar” was established, so that the integration of simulation software into the design process will lead to a new chance for the application of VR in teaching and practice. If this chance is used, the quality of architectural and urban planning solutions designed with the help of VR will at least improve in terms of ecological aspects. The promoted tool, which is still under construction, will make its contribution to this evolution.

2 Simulation

There are different kinds of simulation routines that can be used in architecture and urban planning. With the help of computers, wind fields, cool air discharges, the propagation of air pollutants along the road, the distribution of daylight or artificial lighting in street spaces and buildings, solar energy quantities on building facades, and the propagation of noise in the city can be be simulated, among other things.

Depending on the kind of simulation and the applied algorithms, the effort of computation varies, and the time of calculation differs accordingly. The calibration of initial parameters required for computation may also have a significant influence, but can more or less be optimized for fast computation times depending on the kind of simulation. Only if the simulation routine reacts on design changes within the shortest time and immediately supplies updated results, can it be used within the draft process. A simulation is appropriate for real-time application if the calculation period does not exceed some seconds. Naturally, the hardware should be as new and as fast as possible. However, computing time does not only depend on the technical conditions of the hardware, but can also be accelerated by different software-technical principles.

2.1 Acceleration of RT-Simulations

Simulation results can become less accurate through acceleration. In other words: at the expense of precision, simulations can be accelerated. One principle of acceleration, thus is the use of algorithms that provide rounded values. Simulations can also be accelerated if their algorithms are optimized or simplified, and if the dissolution of computed points is reduced within a certain area. A further acceleration principle is called “nesting-procedure.” Here, the resolution of simulation is gradually increased. With the skillful arrangement of the area that has to be computed, in more or less important zones, the simulation can be divided hierarchically in several computation cycles. An initial rough calculation output is refined gradually in its accuracy at relevant spots. However, the “nesting-procedure” cannot be realized with some kinds of simulation—or just with a huge effort.

Still another principle is the parallelism of simulations. Parallelism means that a simulation run is split into a certain number of packages that will be assigned to different processors. The number of packages is approximately inversely proportional to the computation time of the entire simulation. In extreme cases, only one individual point is computed per package.

Even an excellent simulation can illustrate reality only approximately. Therefore, a fundamental assumption for the realization of real-time simulations within the “r.Vipar”-project is that designers do not need absolute accurate simulation results during the draft process. It is adequate if the simulation computes and shows tendencies at this point. The planner should be able to observe how changes in his design correlate with improvements or degradations in the simulation result. More accurate simulations can still be performed optionally later.

2.2 Selection of the simulation

For this project, we chose a simulation method which can be accelerated by as many of these principles as possible. On noise simulation all of the principles were applicable, and the goal of our project, to develop a tool which provides simulation results in real-time, seemed to be easily realizable. In comparison to other computable phenomena, noise propagation can be calculated quickly. Therefore, we decided to work with Soundplan, a professional simulation software for the computation of noise propagation in urban spaces developed for “MS Windows.”

2.3 Controlling of the Sound Simulation

The company Braunstein & Berndt developed an interface in cooperation with us, so that Soundplan can be controlled by external programs. With the help of this interface, simulation parameters, three-dimensional geometry, points of emission and immission, and the simulation results can be transferred. If buildings are e.g. created, transformed, or removed during a planning session, this will be communicated to the simulation software. The simulation routine starts a new computation procedure after the transmission and provides updated results.

Two calculation proceedings, the “noise-map run” and the “single-point run,” can be released with this interface. During the “noise-map run” the noise levels are simulated for all points of the predefined, structured grid. For the “single-point run” any point in space can be defined, and the noise level at that point will be computed. These two calculation methods differ nearly only in the definition of the points of immission and, therefore, are combinable with each other. The computation of such a single point just takes the fraction of one second on an average PC.

3 Visualization Techniques

Through visualization huge amounts of data become comprehensible easier and faster, and their analysis and evaluation can be accelerated. The kind of visualization has substantial influence on the designer’s perception and can affect his decision making. Therefore, different methods of data visualization and the correlations between data visualization and the process of decision making of architects and city planners have to be examined and tested in the context of this project.

Common forms for the visual representation of noise propagation are horizontal and vertical sections or shades of color on building facades. However, a three-dimensional model of noise immission offers a more comprehensive impression. Especially for people who have to deal with the results of noise propagation but are not familiar with the procedure of their calculation, a three-dimensional representation may be a crucial assistance. Depending on the question, it serves as an indication of critical zones in a scenario. They can be recognized quickly by the user, and thus help to develop a feeling for the behavior of noise propagation. This kind of application of visualization is called “Explorative Analysis.” It should obtain an understanding of the structure of the data and an insight into its correlations. “Scientific Visualization” is the umbrella term for the visualization of complex data records in order to get a better sense for their underlying structure.

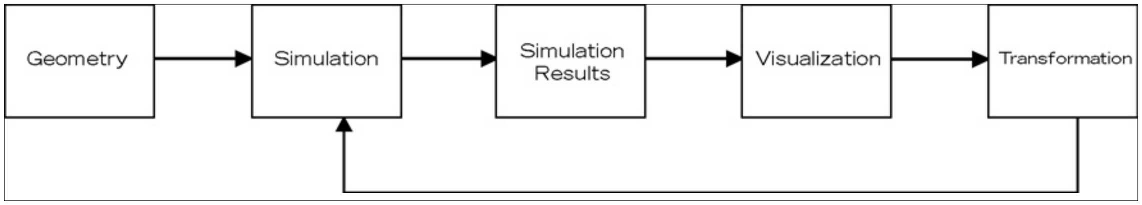

Figure 1. Simulation and Interaction

3.1 Visualization of Noise Propagation in Urban Spaces

Noise propagation in urban spaces is visualized on PC screens as two-dimensional sections through the three-dimensional area of investigation so far. This can be quite reasonable for noise nuisance plans of large areas. If an urban space is to be examined, the vertical structure and the spatial propagation of noise becomes relevant. This can only be examined with a program that offers the ability of simulating and visualizing noise propagation in the third dimension as well.

For the creation of an expertise about the noise level distribution in the city, the noise propagation is usually just computed for one horizontal level at a certain height. For the three-dimensional representation, either several horizontal or vertical sections must be simulated, or a three-dimensional structured or unstructured grid has to be defined that can also be simulated by “single-point runs.” The resulting model can be supplied to a visualization software.

A competent facility with much expertise within the range of “Scientific Visualization” is the visualization department of the High Performance Computing Center Stuttgart (HLRS) at the University of Stuttgart, which is participating in this project. Numerous projects in cooperation with international firms and other research establishments or universities were already accomplished successfully. As a major result of their research and development activities, the HLRS developed a software called COVISE (Collaborative Visualization and Simulation Environment). COVISE was particularly developed for the visualization of three-dimensional simulation data. This program running under the operating system Linux is intended for data visualization on screen and for different kinds of virtual reality media.

3.2 Function Mode of COVISE

Since COVISE is developed with a modular structure, it is easily extendable with Plug-Ins and offers open interfaces for the connection of different simulation programs. We interactively connected Soundplan and COVISE with a particularly developed Plug-In. Some functions of the VUI (Virtual User Interface) of COVISE were extended to a simple VR-Modeler that can be adapted to our desired needs.

3.3 Employment of the VUI

The VR-Modeler is conceived consciously simply. Only a few modeling functions are needed. For example, simple building cuboids (boxes) can be created or removed. They can be transformed (moved, rotated, and scaled) afterwards. Optionally, with each change of the VR model the noise propagation is computed again by the connected sound simulation interactively (Figure 1). The ergonomics of the Modeler should enable sketching in VR in a similar, simpler way than working with e.g. PS (expanded polystyrene) foam which is commonly used by city planners for sketch models within the design phase.

4 Technical Implementation – Status Quo

The software-technical realization is based on the connection of already existing programs. They were linked with each other through the development of extensions and Plug-Ins in order to create an extended, interactive design environment. The developers of the respective programs provide support for the project “r.Vipar” in terms of their know-how.

For the connection of the noise simulation program Soundplan running under MS Windows and the virtual reality software COVISE developed for Linux we had to create a control and data interface with appropriate I/O filters connecting both operating systems. The sound simulation and the VR software are thus running with two different workstations. Controlling is currently based on an SSH interface and will be gradually replaced by an internal protocol.

Geometry and other attributes can be transferred over the interface to the simulation and the result values from the simulation in reverse. It is possible to save conditions of intermediate design results, including all individual settings made, and to export the building geometry as well as the model of the noise propagation as vrml-file. Thus, different situations can be compared with one another later again.

The model of the surrounding area can be optionally created with any CAD-program. Over a DXF interface it can be imported into the sound simulation software. COVISE is able to import DXF-files as well, but can also handle vrml 2.0 format. Any objects created in VR, like buildings or points of immission, will be accounted in the simulation run. They can be picked up and freely moved in space (Figure 3). A new computation of the simulation is started currently by pressing a button in

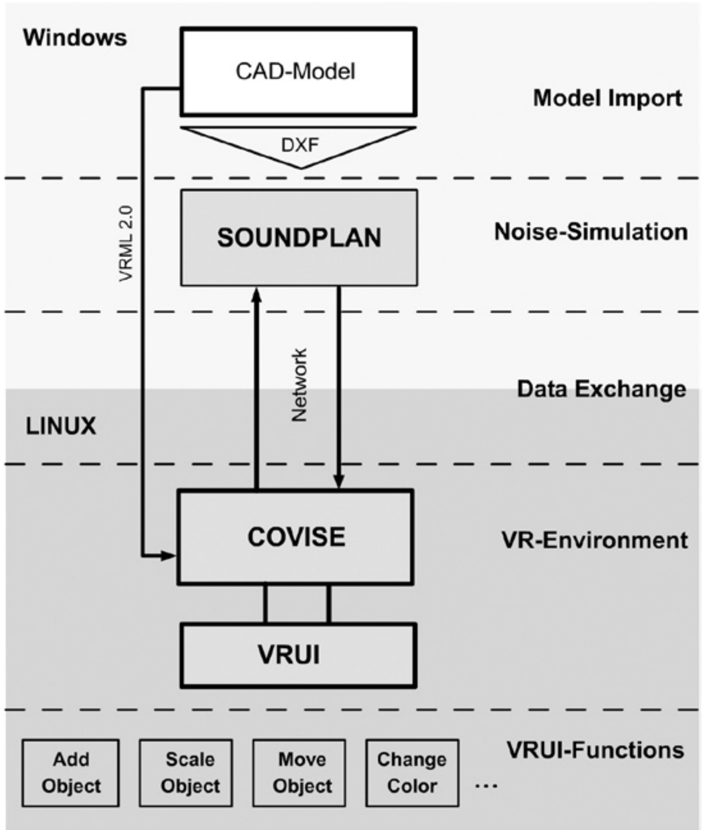

Figure 2.

the VRUI. For the representation of the noise propagation different visualization techniques, like ISO-surfaces or volume rendering, can be used. The shades of color and limit values can be changed over an VRUI interface interactively among other visualization parameters.

5 Intended employment in teachings

5.1 Didactical Concept: the "Open VR"

The faculty of architecture and urban planning at the University of Stuttgart runs a computer pool with approximately 100 CAD workstations over all. Within this pool a "One-Wall" VR installation is going to be set up. This includes a stereo projection wall together with a tracking system that will be operated with similar technology as used in a "CAVE" (Cave Automatic Virtual Environment). This facility should be freely accessible like all the other workstations for collegiate studies. Through this direct access working on VR projects should become more natural. The basics of how to use and work within a VR environment will be taught in classes. Some seminars will concern specific questions regarding the field of architecture, city planning, and virtual reality. Under these conditions the VR-tool developed in the context of "r.Vipar" is to be employed for small design tasks concerning city planning.

5.2 The practice in basic teachings

The developed tool should also be usable for teaching first and second year students. Therefore, a goal is to sensitize them for the topic of scientific simulations through e.g. the simulation of noise propagation in urban spaces. They will learn how to consider ecological aspects within their design process.

6 Outlook

In the further progress of the project, "r.Vipar" the on-line interface will be optimized first. Parallel to that, visualization techniques will be examined, and the VR Modeler will be adapted to the required needs. In the VRUI, it should be possible to define single points of immission as well as structured or unstructured grids. Afterwards, a prototype of the design environment developed in "r.Vipar" is to be used in teaching and thus tested by students.

A next step will be to expand the prototype through an interactive connection with the light simulation program "Lightscape." With the help of this software, it should be possible to integrate the simulation of daylight and artificial light situations into draft planning. A converter has already been developed. It summarizes several output files from "Lightscape" to a "Vrml 2.0" file that can be imported into COVISE. It should become possible to examine shading processes of buildings and to create e.g. zoning plans for city lighting in VR.

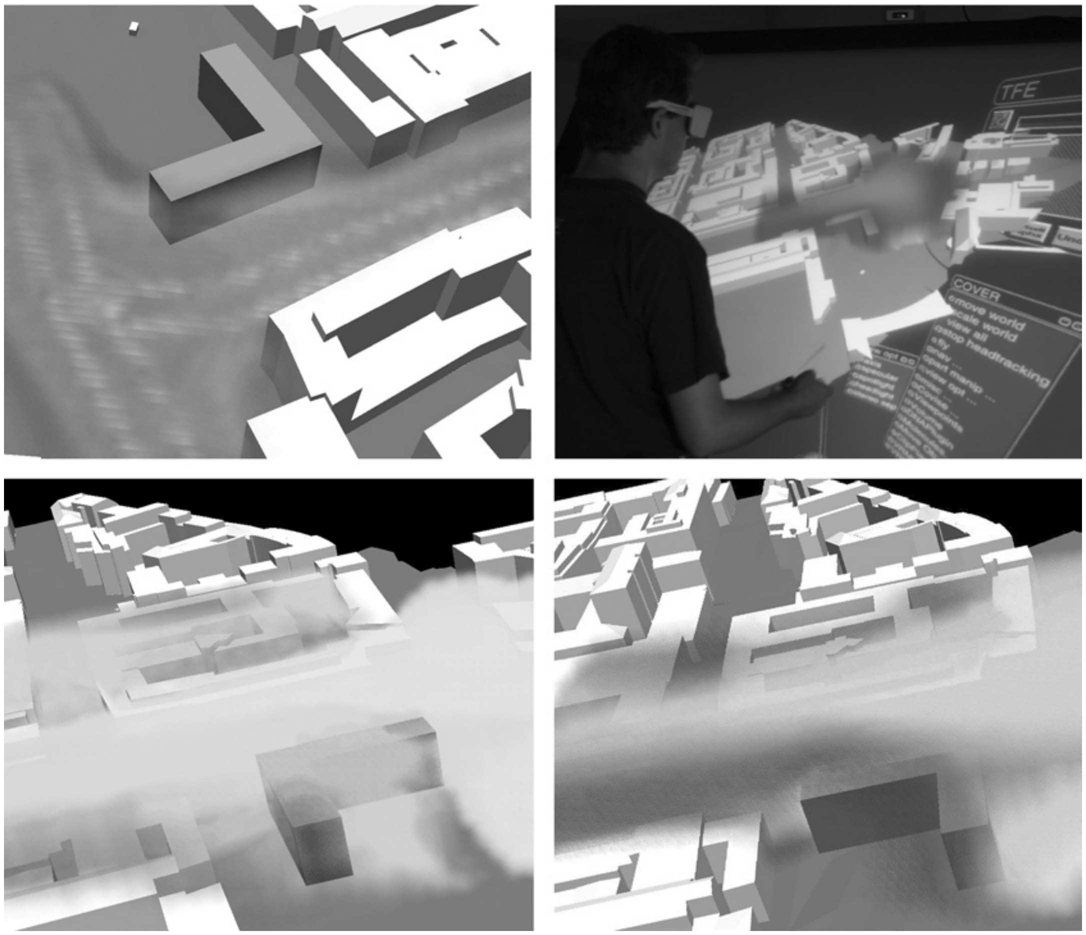

Figure 3.

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