Interactive Simulation of Architecture in Virtual Environments

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Architecture always has an environmental impact. By using simulations, planners can minimize the environmental impact. Since simulations normally take a long time and thus only allow a very limited number of iterations, our project describes the setup of a close-to-real-time simulation technique. By dividing the simulation into smaller parts and running the software on clusters or massively parallel computing platforms, first results are available within several seconds, reasonable results below one minute. In order to make this tool easily accessible to specialists and laymen, a tangible user interface provides an intuitive interaction method. The results of the simulation can be visualized and interacted with in different virtual environments. Limitations, mainly automatic grid generation, shape recognition and computation power are discussed.

Keywords: *Interactive Simulation; Tangible User Interface; Virtual Environment; Virtual Reality*

Buildings have a strong impact on the environment. With current digital simulation techniques the impact can be analysed at very early project stages and thus help planners to evaluate strengths as well as weaknesses of their design. They can work on and change their design to achieve an optimal result.

As optimization is an iterative process, planners have to go through several iterations of design, simulation and evaluation to achieve optimal results. The time to prepare, run and interpret simulations limits the number of iterations and thus the possible quality of the design.

Especially in the architectural practice, simulations are not integrated into the usual workflow. After an initial design, engineers work on the simulations, interpret the results and return recommendations to the architects. Then changes are made and maybe a second iteration of the simulation is run. However this time consuming process is very limiting to find the best possible solution.

In order to decrease the time for these iterations, to reduce possible interpretation errors and give immediate feedback, the authors worked on the integration of these tools in virtual environments and augmented reality test beds. The tools are supposed to enable architects to directly interact with their models and get instant feedback of the simulations as presented in this paper. As an example an airflow simulation is shown, however it can be transferred to other topics alike.

The main intentions of the project were:

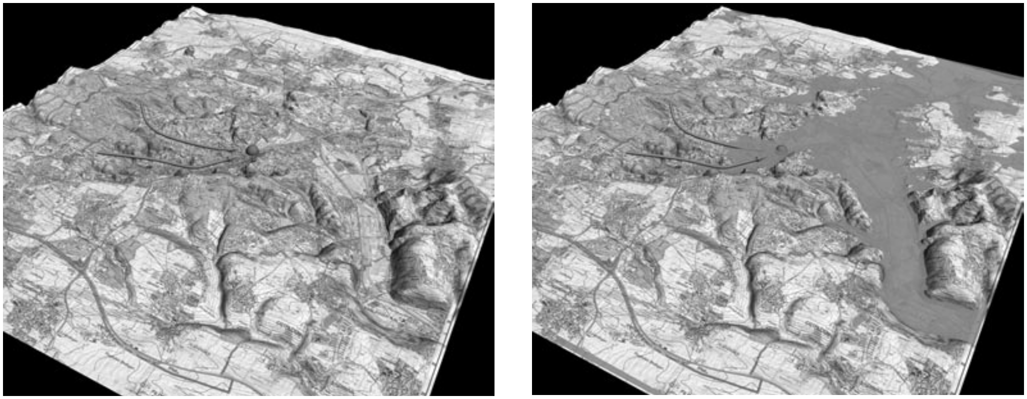


Figure 1
Topography of the city of Stuttgart (z-scaled 5x). Arrows show wind paths, sphere showing the location of the site. The grey surface shows "flooding" of the valley like situation

- to enable simple interaction
- to produce physically correct results
- and give immediate feedback

Project description

The urban situation of the city of Stuttgart is the test bed for the application. Stuttgart is located in a valley like situation surrounded by plateaus. Due to this topography the air pollution, especially in inverse weather conditions, tends to become bad. In order to limit the impact of the built environment, building regulations restrict higher buildings and building orientation in order not to impair the natural airflow.

"Stuttgart 21" is a project changing the main railway station, currently a dead end station, to become a through station. For this new through station, railway lines will be built one level below ground with long connecting tunnels orthogonal to the current lines. Thus a large area close to the city center (in above figure right behind the sphere), currently occupied by the railway lines, will become available as building land. In order to evaluate the impact and chances of the new area, the project provides an interface and close to real time simulation to study different arrangements of buildings and their positive and negative impacts on the city climate.

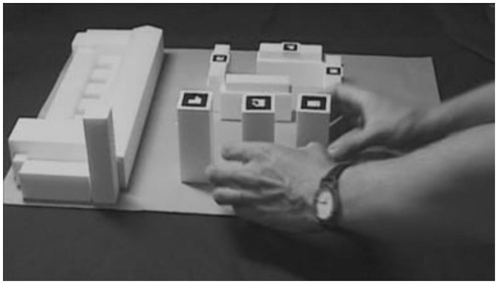


Figure 2
Tangible interface to interact with simulations

Interactions and interface

There are numerous approaches of interacting with simulations. In this project a "tangible user interface" best covers the need to make interacting with the simulation easy for specialists as well as laymen. Through the manipulation of physical objects representing interactions for the simulation and buildings, users can control the simulation as well as the visualization. Advantages of tangible user interfaces for example are the very clear way that objects are represented. The interaction is very simple due to the fact that it is close to reality and tangible user interfaces can be used in all environments, from desktop systems to virtual environments.

Flow of data

As in usual virtual reality visualization, the 3D data is transferred to a modeling package (e.g. 3D Studio

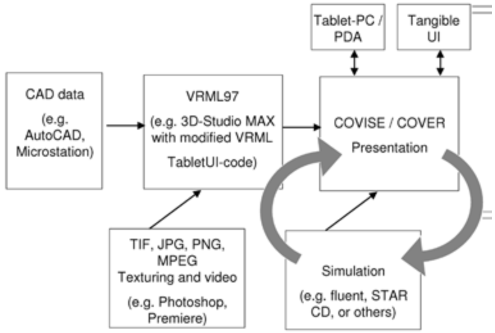


Figure 3
Flow of data

MAX). To apply mappings the model is then exported to the VR software system, in our case as VRML97 dataset. The VR framework OpenCOVER provides all necessary interaction techniques and can be directly coupled to the simulation. Changes like moving elements in the tangible user interface are transferred to the simulation in order to get new results from the simulation.

Simulation workflow

The typical simulation workflow is:

- Model interaction (move building or interaction-markers in model)
- Geometry generation (generation of a 3D surface model)
- Grid generation (derivation of a computational mesh)
- Domain decomposition (subdivide mesh into small parts for a parallel simulation)
- Solver (compute the simulation)
- Post Processing (visualization) and
- Analysis (interpret the results e.g. on a screen or in a CAVE).

Model interaction

A digital camera is mounted vertically above the physical model with the video image matched to the planning area. Using AR Toolkit (Billinghurst et al, 2001), markers with different patterns are tracked, each representing either an element to directly interact with the simulation through moving buildings or changing boundary conditions like wind direction or they allow to interact with the visualization, e.g. place cutting planes or start particle traces.

Geometry generation (generation of a 3D surface model)

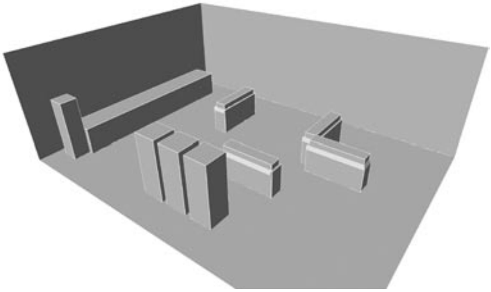
The digital camera tracks the position of the markers. Each marker is directly linked to a building geometry, so the system generates the geometry from the position of the markers.

Grid generation (derivation of a computational mesh)

For the simulation, a computational mesh based on hexahedral elements is required. Based on the position of the tracked elements, an unstructured grid is generated automatically. The grid generation algorithm uses a subtractive approach, detracting the volumes (elements and nodes) from the full grid. In order to attach the grid to the surfaces of the build-

Figure 4
Moving markers (symbol elements) to interact with the simulation or geometry

Figure 5
Digital representation of the geometry generated based on the markers



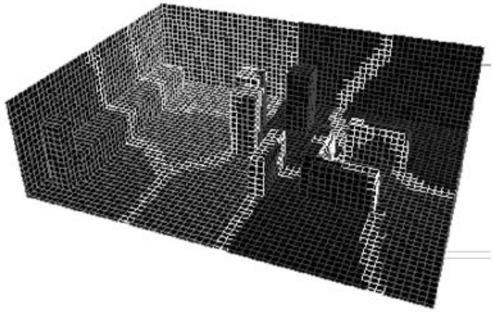


Figure 7
Domain decomposition dividing the model for eight nodes

ings, the nodes are shifted adjacent to these surfaces. The grid size can range from approximately 100.000 elements for interactive response times to millions of elements for a more accurate, however more time consuming calculation. The modeled building area in this project is about 250 x 300 meters. Boundary condition is a wind profile with low speed on the ground and higher towards the top of the grid. The wind direction can be changed interactively.

Domain decomposition (subdivide mesh into small parts for a parallel simulation)

To speed up the calculation, the computational grid is divided into several parts for parallel processing on a cluster of computers. Each area in the following figure shows the grid calculated by one node as well as the connecting cells, at which information is exchanged between the nodes. The library for the partitioning of the mesh is METIS - Unstructured Graph Partitioning and Sparse Matrix Ordering System (Karypis and Kumar, 1995).

Solver

As a solver for the CFD (computational fluid dynamics) calculation the software FENFLOSS, developed by the Institute of Fluid Mechanics and Hydraulic Machinery, University of Stuttgart is used. FENFLOSS can calculate laminar and turbulent flows, running on PCs, PC clusters as well as massively parallel computing platforms.

Post Processing

Several modules and plugins in COVISE as shown in the previous figure are needed to visualize the results. Separated from the visualization, the simulation is a process of its own. After each global iteration this process sends new data to COVISE, which means every few seconds. About 10 to 20 seconds after starting the simulation, first and very rough results of the simulation are shown. The following

Figure 6
Part of the computational grid (cell size 3 x 3m)

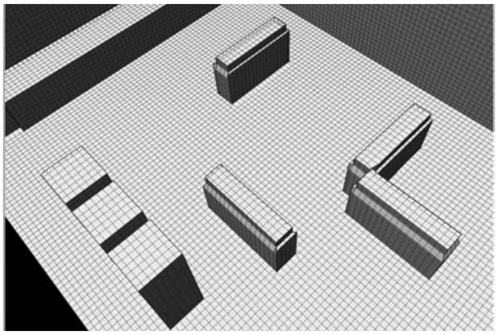


Figure 8
One possible calculation platform, NEC SX8 at the HLRS

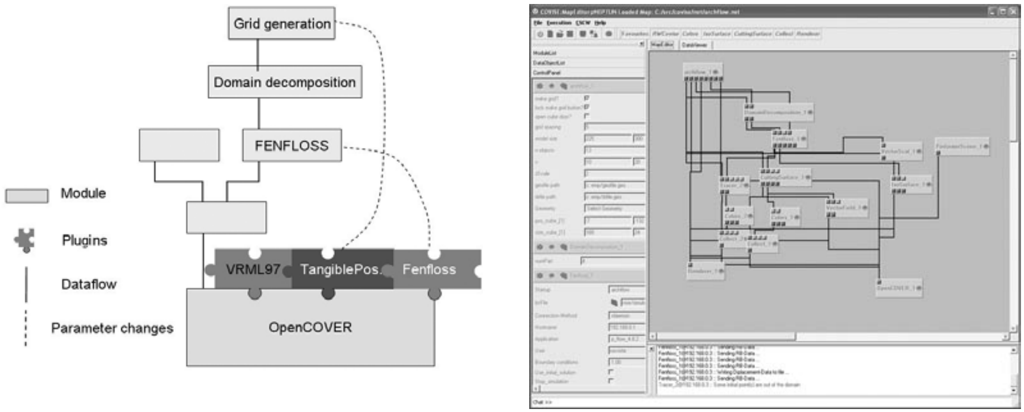


Figure 9
Overview of plugins and modules in COVISE; COVISE user interface with dataflow network

iterations take about 3 to 5 seconds. So within about one minute, a sufficiently exact result can be expected. Hence a first impression of the situation is given within seconds with a constantly increasing quality of the simulation results later on.

Analysis

On the desktop or in virtual environments like a CAVE, the results can be represented and analysed. COVISE provides different analysing methods like trajectories with colour showing the wind speed, particles or isobar surfaces. Due to three dimensional navigation possibilities and stereoscopic view, virtual environments like a powerwall or CAVE are the best analysing environments.

Further aspects

By changing the building configuration and starting a new iteration process at any time and several times, designers get “a feeling” of how their changing the parameters increases or decreases the quality of the environmental impacts. Thus they can work on finding the optimal shape and position of their buildings.

Visualization of the results in immersive virtual environments such as a CAVE helps understanding complex 3D phenomena and places the simulation results in the right context of the architectural design. By coupling virtual environments through the internet, clients at any place in the world can

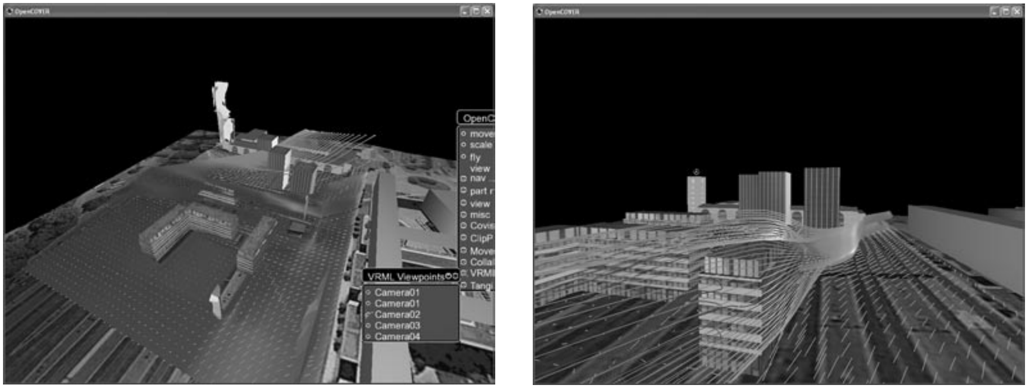


Figure 10
Different representations of simulation results

be involved in the design process or remote experts can be invited for consultation. They would see the results and could interact with the simulation, since the main approach of COVISE is "Collaborative VIsualisation and SImulation Environment". Interaction is possible from all sites, either through their own tangible interface, a virtual environment or by changing parameters in the standard desktop user interface.

Limitations

Even though the current steps of this technology look promising, it has still limitations that should be overcome in the future. The complex behavior of natural systems and its digital representation still needs better models and more computational power. Complex architectural shapes e.g. coming from automatic shape recognition of the architectural model require a more sophisticated grid generation but would make the tool even more productive.

Automatic generation of an effective grid is still one of the limiting factors, so in this test bed the building volumes can not be transferred directly from the VRML-model of the site but have to be defined separately. They have to be defined as cuboid volumes in the simulation beforehand. Furthermore their alignment with the grid is still limited to orthogonal setups.

Due to the calculation and simulation time, one has to decide between both a fine grid with very detailed results and a rougher grid. Whereas the fine grid takes a longer time not being very interactive, the rougher grid allows close to real time results. So in this setup the airflow can be judged in the urban context but not in more detail.

Conclusion

This project shows that close to real time simulation with interfaces that are simple and intuitive to use, can assist planners in optimizing their design. Since they can go through several iterations, they get a deep understanding of how the system works. By providing a platform that can easily be used by all project participants from laymen to specialists, the knowledge about e.g. airflow is not restricted to a small group of specialists but can be exploited by all participants.

However coupling of the different software packages and running it on clusters or supercomputers still needs a lot more work. With increased computational power accessible to end users through standardized grid services and advanced automatic grid generators, interactive simulation can become a tool that planners might use in their everyday business to substantially improve the quality of their projects.

While this project shows airflow simulation, further simulations like light simulation or noise simulation will increase the quality of the projects.

References

Billinghurst, M., Kato, H., Poupyrev, I.: 2001, The MagicBook: A Transitional AR Interface..Computers and Graphics, November 2001, pp. 745-753.

Karypis, G; Kumar, V.: 1995, Metis - unstructured graph partitioning an sparse matrix ordering system. Technical report, Department of Computer Science, University of Minnesota, Minneapolis, MN, http://www.cs.umn.edu/~karypis/metis.

Lang, U., Wössner U.: 2004, Virtual and Augmented Reality Developments for Engineering Applications" In Proceedings of European Congress on Computational Methods in Applied Sciences and Engineering ECCOMAS 2004, Jyväskylä.

Volbracht, S.; Domik, G.: 2000, Developing Effective Navigation Techniques in Virtual 3D Environments, Virtual Environments 2000 [Proceedings of the Eurographics Workshop]. Amsterdam (Netherlands) pp. 55-64.

Wolf, R.; Yaeger, L.: 1993, Visualization of natural phenomena.Santa Clara: TELOS.

Wössner U., Kieferle J.: 2004, Interaction Methods for Architecture in Virtual Environments' ,Proc of the eCAADe 2004, Copenhagen,Denmark.