TOWARDS A UNIVERSAL AND INTEGRATED DIGITAL REPRESENTATION OF PHYSICAL PHENOMENA

A model to investigate comfort and energy efficiency in future environments

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Abstract

This thesis describes the exploration and the development of computational means to investigate the behaviour of design objects before they are available for investigation in the physical world. The motivation is to inform the design process about the design object's performance in order to achieve better – more performance-oriented – design outcomes in the sense of energy efficiency and comfort performance than can be achieved by conventional design techniques.

The research is structured into five successive parts.

- *Concept Development* – A review of the objective domains comfort assessment and energy efficiency assessment is conducted and the design process, human design activity and the application of simulation in the architectural domain is discussed in order to identify requirements for the development of computational means for design analysis. Requirements regarding model content, model features and model integration are developed. The main requirements are that a highly integrated, three-dimensional and dynamic representation of physical processes is needed and that a universal and integrated representation is required.
- *Concept Formulation* – Based on the identified requirements, the concept for a model is formulated. In order to achieve a universal and integrated representation of physical processes the concept uses the approach of a constructive language. Space is represented with autonomous spatial elements, called congeneric cells. Interaction between the cells is represented by near- and remote-conjunctions. Physical and geometric self-contained formulations of the model reduce the model input requirements, so that geometric information and simple property specification (material, activity) is sufficient to describe the design object in the model.
- *Model Development* – The concept is formulated in mathematical physical terms based on well known physical laws and building physical models (first-principle approach). Heat and moisture conduction, diffusion of various components and a flow model is formulated as near-conjunction processes. Heat radiation, light and sound are modelled with a radiosity approach as remote-conjunctions. The simulation algorithm, which governs the interaction between the cells in order to represent the behaviour of space, is explained.
- *Computational Implementation* – The concept and the model is tested by implementation of a prototype using C++ and OpenGL on a conventional Pentium 4 notebook. The prototype consists of three parts: user-interface, model translator and simulation engine. The user interface functions as model-input and result-output device. The implementation of the concept and of further model parts is described in detail.
- *Assessment and Testing* – The developed concept and the model, as implemented in the prototype, are tested and assessed against the initially developed requirements. The physical model is assessed in regard to plausibility and accuracy of the representation of the physical phenomena.

At the end of the thesis the project is summarized, the achievements of the project's objectives are discussed critically and issues for future research are suggested. Possible applications of the developed model are listed, and the contributions to the application of computational simulation in the architectural domain, developed in this research, are named.

At the current stage the required processing time and high memory requirements prevent implementation of a design assessment system, following the suggested concept, at a useful scale. Also the developed physical models require further refinement and testing. Although

the general feasibility of the concept and the model was successfully demonstrated, its implementation in a fully applicable design assessment system based on the universal and integrated representation of physical processes was not achieved at this stage.

While detailed description and analysis is given in the body of the thesis, detailed formulations of the work and the developed model are given in the appendix. The body and the appendix together provide a complete picture of the research presented.

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