Simulation for Analysis: Requirements from Architectural Design

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Abstract

Design analysis has been traditionally performed according to normative rule-based systems. Simulations where designs can be examined intuitively in full detail and at the same time by quantitative models are preferable, as they extend to issues inadequately covered by normative analyses such as dynamic aspects of design. Given the variability in the form of designs and in the possible users, testing prototypical designs by typical users is insufficient for arriving at globally acceptable new solutions. Instead, we should test each design individually in its own context. To this purpose we need a fusion of computational and analogue technologies for full scale simulation. By registering the actions of a large number of test persons in a full scale laboratory through motion capture we derive a sufficiently varied number of user profiles. These profiles subsequently drive virtual humans for testing computer simulations of the built environment with the precision, accuracy and reliability current design problems deserve.

Design, Analysis and Simulation

Design analysis and design theory are traditionally geared to generative approaches. The numerous analyses of the design process have resulted into a multiplicity of models which attempt to describe the steps a designer takes in the quest for a satisfactory solution. Most models also aspire to prescribe the optimal sequence of design actions. What they propagate is a form of orthopraxy (as opposed to the orthodoxy of formal systems such as the Classicism and the Modernism). Their underlying assumption is that if one follows the sequence of design stages prescribed in the model, they can arrive at a design that satisfies the programmatic requirements.

It is unfortunate that no such model to-date can match the intuitive performance and creativity of the human designer. Being based on metaphors and similes, most models do little beyond explain a few specific aspects of designing. Moreover, while they may improve the designer‘s awareness of their actions and decisions, they seldom lead to the development of new, sharper tools for higher effectiveness and reliability in the face of today‘s complex design problems. Perhaps the main reason for the scarcity of such tools lies in the relative lack of interest in the analysis of design products.

Historically such analysis has been subservient to synthesis. Long before terms such as functional analysis and programmatic analysis were invented, buildings and design decisions were being parsed towards an identification of their causes and effects. These were subsequently formalized into rules and stereotypical „good“ solutions which served as the basis of most building regulations and design textbooks. Rules and stereotypes have mostly a proscriptive function. They attempt to offer design guidance by pointing out errors and inadequacies, i.e. what falls short of the established norms.

The proscriptive approach also underlies computational studies which focus on the analysis of designs using the same or similar rules transformed into expert or knowledge-based systems. In these a design is described in a piecemeal fashion which permits correlation of the relevant aspects or factors with the rules. The end product of the analysis is an acceptability test based on the matching to the constraints of the solution space. The added value of such systems lies in the provision of feedback which facilitates identification of possible failure causes.

Other computational studies rely on mathematical models for the measurement of projected values and patterns in a design. These have been applied mostly to environmental aspects and constitute a significant promise for improving the designer‘s instruments. However, computer systems which derive from such studies have long remained first-generation attempts, hampered by their reliance on models which are insufficient for projecting the behaviour and performance of a design with accuracy and precision [1].

Our working hypothesis is that design analysis is moving towards a new paradigm, based more on simulation than on abstractions derived from legal or professional rules and norms. Recent developments in areas such as scientific visualization offer advanced mathematical and computational tools for achieving high detail and exactness, as well as feedback for design guidance. The close correlation of photorealistic and analytical representations (figures 1 and 2) clarifies and demystifies the designer‘s insights and intuitions. Moreover, the combination of intuitive and quantitative evaluation offers a platform of effective and reliable communication with other engineers who contribute to the design of specific aspects.

The more abstract rule systems that underlie norms and regulations remain for the moment as a higher level of abstraction. Their utility in a multilevel analysis approach is twofold [2]. Firstly, they permit direct matching of a design to the legal minimal requirements. This is obviously an inescapable obligation of the designer. Secondly, the comparison of rule-based analysis with

Fig. 1 Photorealistic light simulation (Radiance image by A.M.J. Post, Delft).

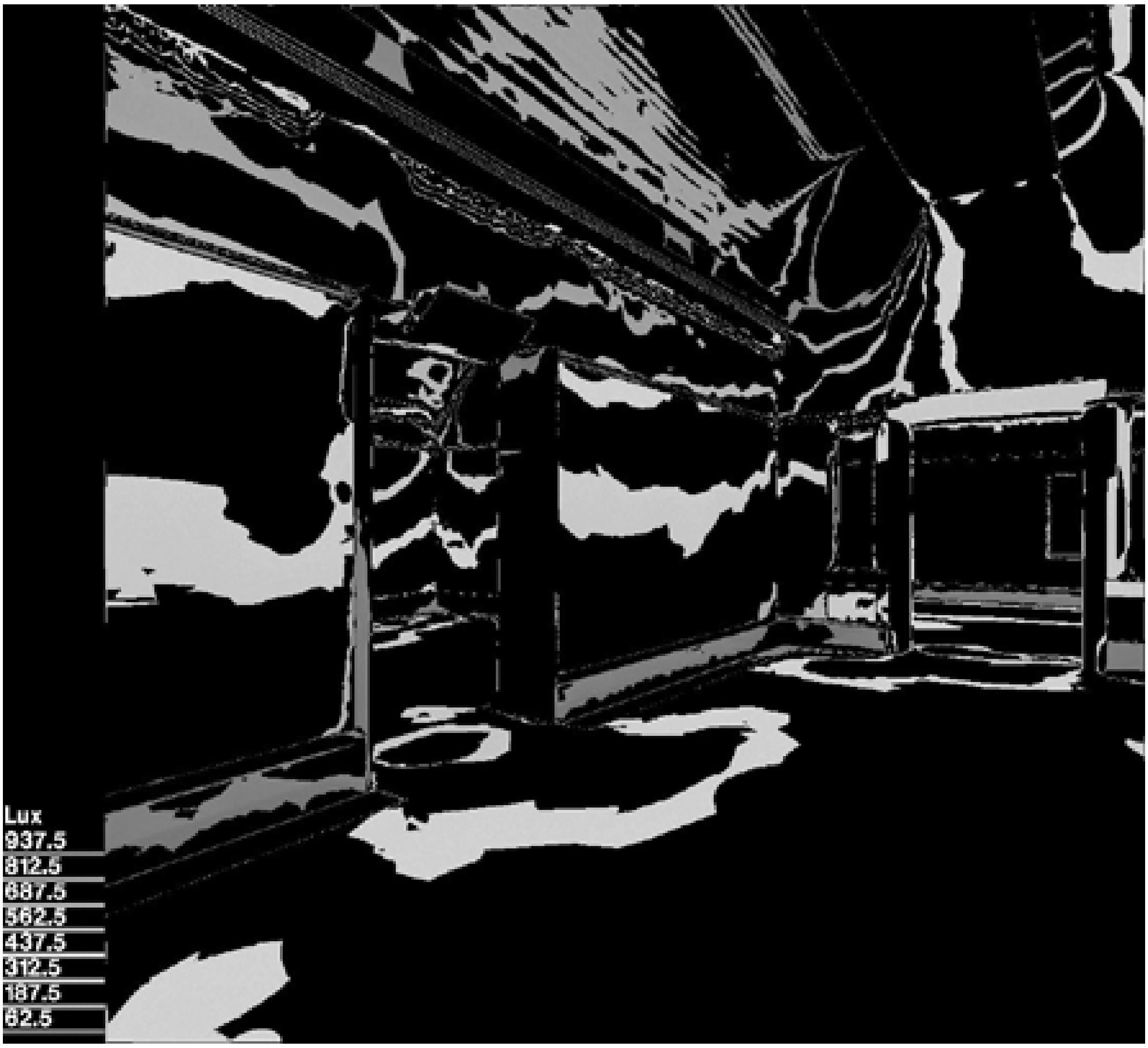

Fig. 2 Light simulation: intensity analysis in the space of figure 1 (by A.M.J. Post).

simulation points out the shortcomings of the former and hence the foci of more precise and accurate analysis. The reverse is more doubtful. The possibility that current rule systems can suggest ways of abstracting simulation results should be treated with caution so as to avoid deterministic searches for verification and validation of outdated, inadequate approaches. For example, acceptance of the underlying principles of fire escape in building codes and regulations provides a distorted picture of human behaviour (see figures 3 and 4) which can be corrected by subsequent analysis by simulation (figure 5) [2]. The same applies to human movement on stairs. The logic of Blondel‘s formula and of its epigoni fails to account for human flexibility and adaptability, as well as for failures in designs firmly based on such formulae [3, 4].

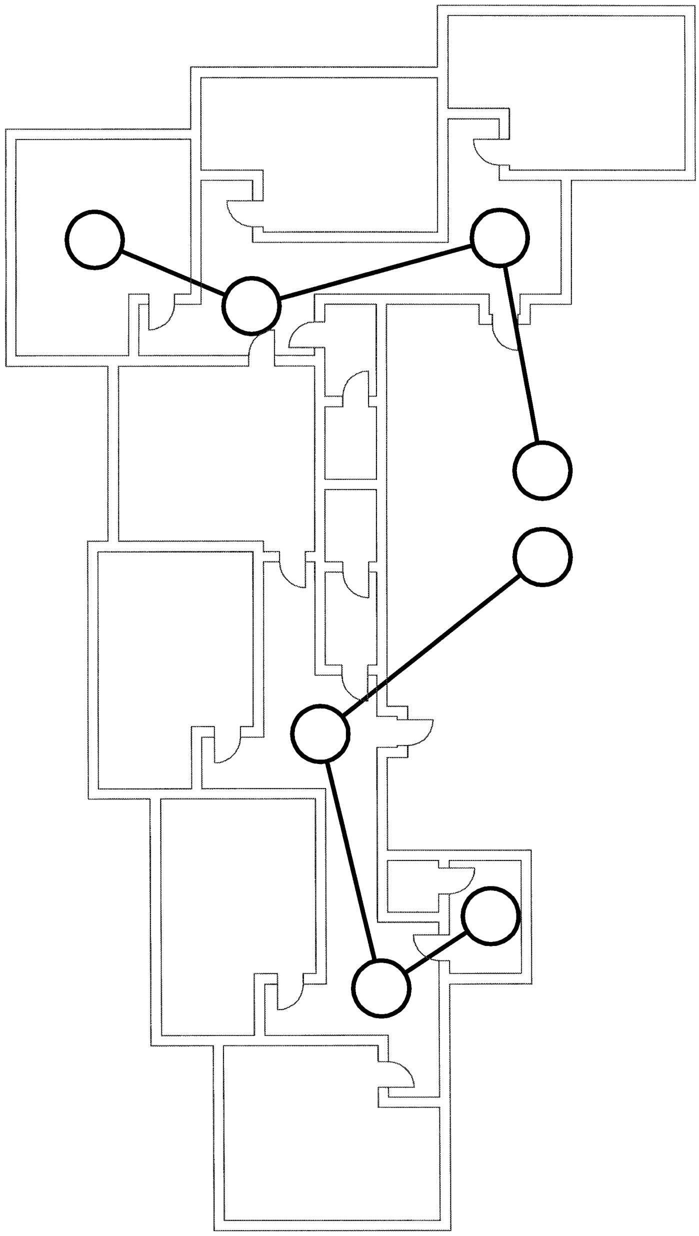

Fig. 3 Topological escape routes: normative analysis at a high level of abstraction.

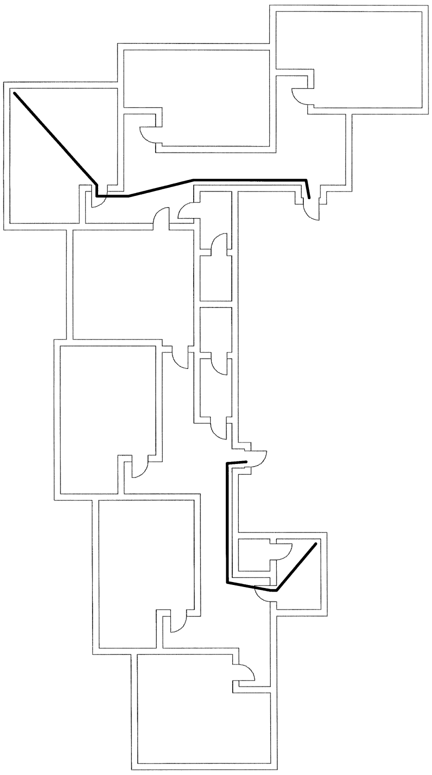

Fig. 4 Geometric shortest routes corresponding to the patterns in figure 3.

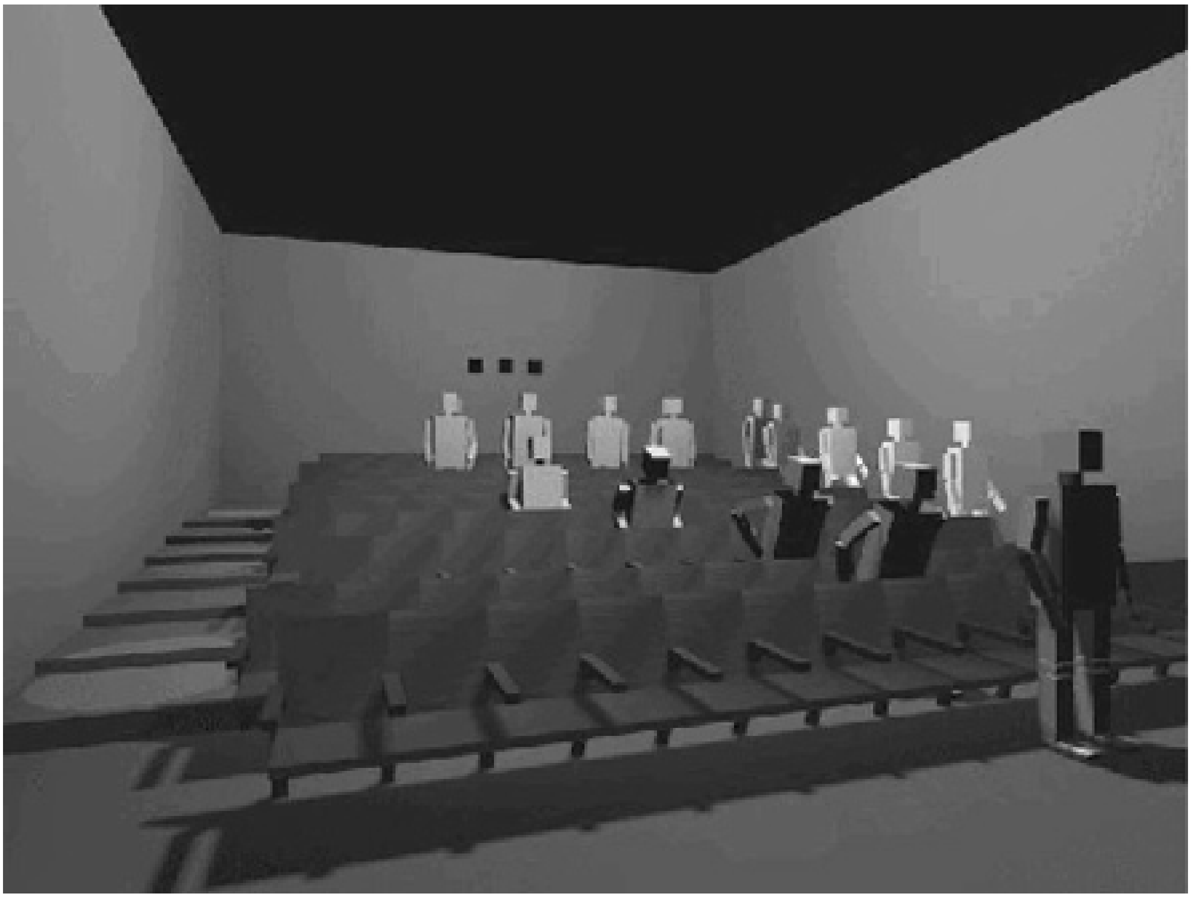

Fig. 5 Simulation of human movement in fire escape (by H. van der Horst, Delft).

The Simulation of the Built Environment

Most simulation techniques provide amply for the detailed and realistic representation of the built environment. There is an abundance of modeling facilities which provide the basis for photorealistic visualization, often in relation to analytical representations, as in scientific visualization (figures 1 and 2). While these systems support intuitive evaluation and communication with other members of the design team, clients and prospective users, interaction with the models is hampered by the structure of the geometric models.

The main difficulty lies in the correspondence (or lack thereof) between mental design representations and the representations used in the simulation systems. The latter are generally derived from analogue implementation mechanisms used for the former [5]. As a result, the designer manipulates geometric objects such as lines and planes instead of interacting directly with design entities, such as the spaces of a building and the building elements that bound the spaces, let alone more abstract spatial or structural patterns [6]. It is possible that current approaches, based on redundant user input and data integrity and exchange, are ultimately incapable of supplying the desired combination of abstraction and specificity which characterizes the use of multiple partial representations connected to each other through recognition [7].

On the positive side, recent developments in rapid prototyping bridge the distance between analogue and digital simulations. Beyond its obvious industrial significance, this also supports a fuller examination and evaluation of design products. Instead of creating a virtual environment for presenting and analysing a new design, the designer can produce a full size mock-up of the design for the actual situation. This is of particular significance for the inclusion of human activities in the simulation.

The Simulation of the Users of the Built Environment

The complexity, variability and adaptability of human behaviour are good reasons for attempting to abstract human activities in the built environment into norms, constraints and rules of thumb. However, such abstractions fail miserably, even under conditions that may be considered normal but yet fall outside the scope of a norm or rule. For example, Blondel’s formula for the geometry of stair dimensions (2 x riser + going = one step) cannot account for the intricacies of lower limb movement in stair ascent or descent or for the differences between the two [3]. It is therefore hardly surprising that, when applied to extreme conditions, such a formula produces unusable results.

Current simulation techniques have done much to produce realistic models of human movement in the computer. Still, even the most advanced models are not yet sufficiently detailed for an accurate projection of how a human interacts physically with the built environment. Moreover, most models refer to canonical sizes and conditions which may preclude the analysis of a design with users characterized by different mobility patterns, in particular children and the elderly.

Such problems can be directly alleviated by the use of motion capture to register the movements of test persons belonging to the different types of possible users of a design. The capture results can be linked to the basic models so as to derive a variety of profiles that represent the complete spectrum of kinesiologic possibilities, as well as sequences of actions that represent reactions to a certain event at a certain place. Such sequences can be an important addition to existing models of e.g. wayfinding behaviour at the onset of a fire escape route (figure 5).

Simulation, Registration and Analysis

The improvement of the built environment that can be achieved by the integration of better analyses in its design relies on the inventive and effective combination of existing technologies. In this combination the marriage of analogue and digital techniques plays an important role, as it facilitates the analysis of human activities in virtual environments.

The first problem that must be resolved concerns the derivation of information on the potential users of the built environment. Full scale analogue simulations can be used to register the behaviour of test persons that can be considered representative of the potential users. In the case of localized problems such as stair design and analysis, we can build a number of stairs with different forms and dimensions (typical and extreme sizes) and use motion capture to record the ascent and descent of real users of all ages, sizes and mobility categories. The recorded data are then collected in typical user profiles linked to models of human movement. Electronic publication of the profiles, e.g. on the Internet, makes possible their use for testing stair designs by means of simulations of virtual humans on the stairs. Mismatches between the movement expectations of the virtual humans and the stair form indicate possible fall dangers that deserve the designer‘s attention.

User profiles for larger scale problems, such as fire escape, can be derived in hybrid contexts, where full scale simulations (for test person movement) are complemented by virtual reality systems (for visual input). Obviously the complexity and specificity of such contexts means that they are purpose built, each for a specific design. Generalizing the behavioral data recorded in these contexts is therefore a tougher proposition than in the localized problems. Nevertheless, the methodology of precedent and case based design can be applied to derive virtual human profiles from related design problems.

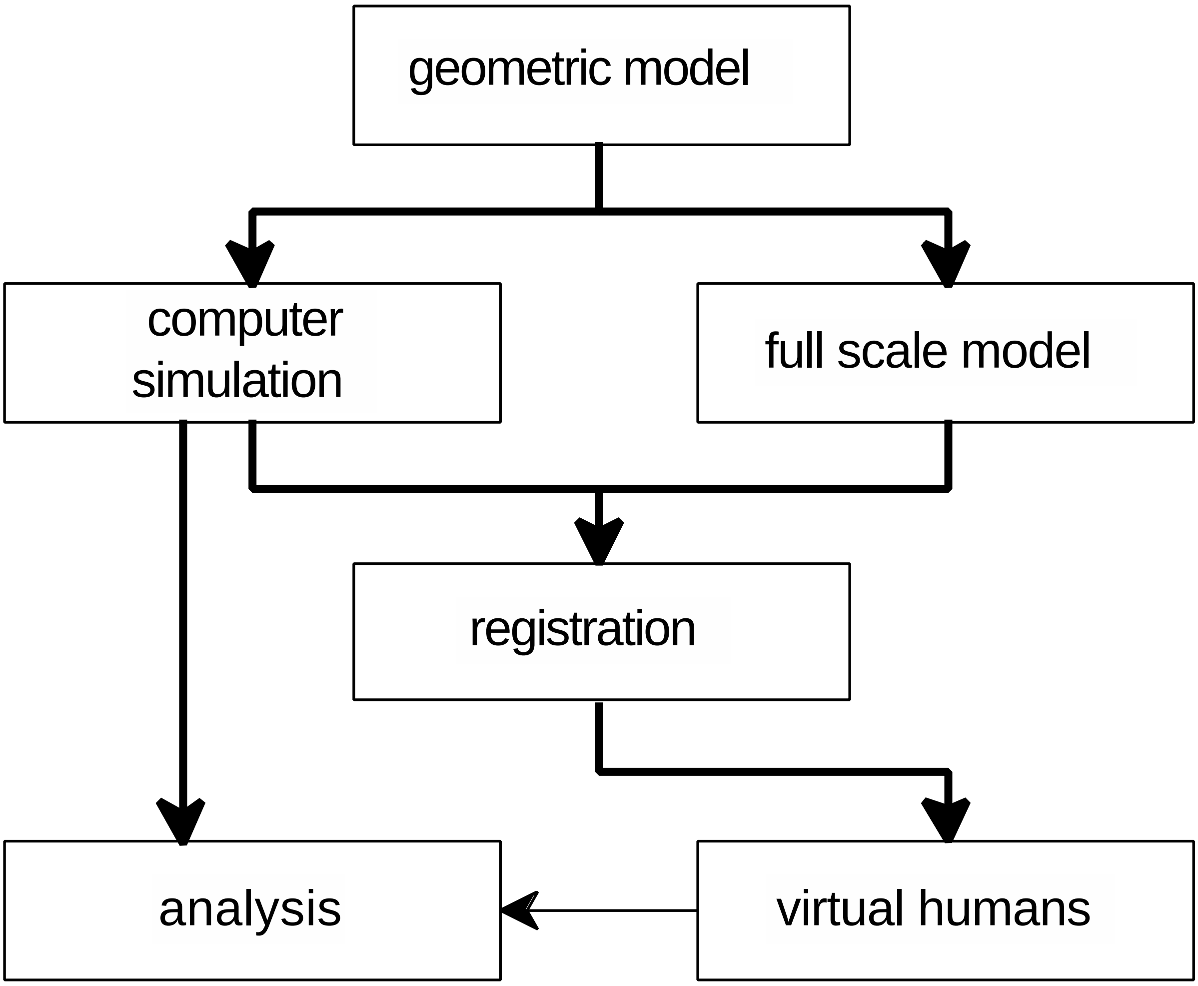

Fig. 6 Outline of the proposed approach.

The proposed approach asks for more than the combination of existing tools. The bringing together of different disciplines and specializations, from functional analysis and full scale modeling to computer science and kinesiology, presupposes a coherent framework of methods and techniques. It is questionable whether this framework can be derived from domain theories and general design or engineering methodology, even though these form a useful background to multidisciplinary communication. Concentration on specific problems which lend themselves to the approach may be preferable, as an exploration of the scope and constraints of the approach but also as an endeavour that leads to direct results: new design tools for practice.

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