# AI: DOES IT HAVE A PLACE IN BUILDING SIMULATION?

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ABSTRACT-Artificial intelligence (Al) technologies and simulation technologies can be combined to support excellent decisions throughout the whole building process. AI technologies are briefly reviewed. Simulation is generalized as a means to predict building performance whether In the building process or in the response of the building in use to its natural and man-made environments. Al can assist the decision maker in selecting the simulation scheme, detailing and conducting the simulation, and assessing the validity and meaning of the results of simulation. Simulation can assist the knowledge engineer in the formulation of knowledge bases to guide in decision making for various building problems. Al and simulation technologies are identified as natural and powerful partners for the guidance of decision makers in all phases of the building process. Substantial research, development, and education will be required to realize the potential of these technologies to increase the usefulness, safety, and economy of buildings.

Keywords: Analysis, Artificial Intelligence, Building, Building Technology, Construction, Design, Expert Systems, Knowledge Engineering, Simulation

## INTRODUCTION

Intelligence is essential to useful simulation, for either the primary definition of simulation "pretending; feigning," or our meaning here of predicting the behavior of a real building. An analyst's expertise includes selection of the modeling method, representing the real situation in the model world, executing the modeling technique, interpreting the results for their validity and significance, and recommending decisions or actions based on the situation and results. Great expertise, involving both technical and social knowledge and judgment, is required for large, complex or unusual simulations. Can artificial intelligence reduce requirements for human expertise or increase the human expert's productivity? This paper addresses this issue and goes beyond to tell how artifical intelligence and simulation technologies are natural partners for the support of excellent decisions throughout the whole building process.

Artificial intelligence technologies are advancing into the marketplace in areas of computer vision systems, natural language programs, and expert systems [1]. While natural language technologies [2] could assist in man-machine interaction in building simulation, and computer vision technologies [3] may be helpful in input and output for simulation, attention here focuses on the role of expert systems with simulation in the building process.

Feigenbaum [4] describes expert systems:

> An "expert system" is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field.
>
> The knowledge of an expert system consists of facts and heuristics. The "facts" constitute a body of information that is widely shared, publicly available, and generally agreed upon by experts in a field. The "heuristics" are mostly private, little-discussed rules of good judgment (rules of plausible reasoning, rules of good guessing) that characterize expert-level decision making in the field. The performance level of an expert system is primarily a function of the size and quality of the knowledge base that it possesses.

Engineers readily can grasp the concept and potential for expert systems. An expert system can be a computer representation of an engineering standard. Does not an engineering standard consist of facts and judgments representing expert-level (the standard committee's) decision making within the standard's scope? Therefore, without exploring the internal mechanisms of expert systems (for this see [4] or [5]), we can look functionally into the roles of expert systems and simulation.

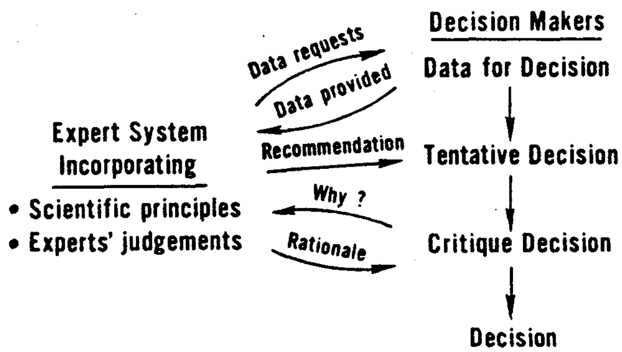


Figure 1. Expert Systems as an Aid to Decision Making

making. Figure 1 represents the interactions between user and expert system. The user supplies data on the problem at hand, the expert system processes the data, may ask for more, and eventually makes a recommendation. The user may (should) query the rationale of the recommendation, and then use it as a basis for decision or for restatement of the problem. Note this view does not ask the expert system for decisions, but for guidance in decisions. The same view can be held for the use of engineering standards or of an expert consultant.

In further development here, knowledge engineering (KE) is used to denote the process of developing and organizing facts and judgments to constitute an expert system, and knowledge system (KS) is used to denote an expert system.

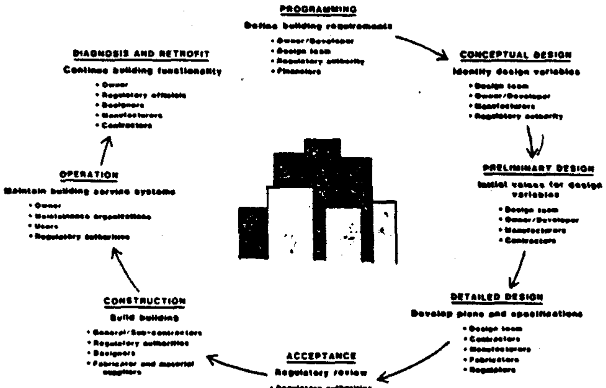


Figure 2. The Building Process

The potential for AI and simulation is viewed in the context of the whole building process. The building process is considered to begin when the need for the building is first formulated and to continue until the building is demolished. In a simplified, linear model shown in Figure 2 the stages of the building process to be discussed are:

1. Programming: formulating requirements and criteria for the building such as the amount of space required for each activity and the extremes of weather to be designed for.
2. Conceptual Design: selecting the schemes for each subsystem such as the shape of the building and types of HVAC equipment. Conceptual design identifies the design variables.
3. Preliminary Design: selecting initial values for each design variable to provide bases for detailed simulation and detailed design.
4. Detailed Design: selecting final values for each design variable and preparing plans and specifications for procurement and construction.
5. Acceptance: review and acceptance of design by cognizant regulatory authorities; testing and approving compliance of materials, components and installation with plans and specifications.
preparation, materials storage, handling and placement, fabrication and finishing.
7. Operation: operating and controlling building systems under normal (ordinary functional and environmental changes) and extraordinary (e.g., a fire emergency) conditions.
8. Diagnosis and Retrofit: assessing and remedying causes of operational malfunctions.

As decisions proceed throughout the building process, relatively more of the information is "facts" and less "heuristics." However, we will see substantial potential roles for AI through all stages of the building process.

Additional stages or activities can be identified for the building process. However incomplete, these shown provide a rich environment for the synergistic application of AI and simulation in the building process.

## AI AND SIMULATION IN THE BUILDING PROCESS

Each stage of the building process is reviewed to identify opportunities for applications of AI and simulation to improve the effectiveness and the efficiency of the building process. Effectiveness denotes the usefulness, safety, and economy of the building throughout its whole life cycle. Efficiency denotes the economy and productivity of the building team in each stage of the process.

Present applications of simulation and artificial intelligence tend to support the detailed design and construction stages where voluminous data processing requirements have stimulated early applications of automatic computation. However, the most critical design decisions, which establish most of project costs and values, are made early in the process during programming and conceptual design stages [6]. AI and simulation have great potential for improving early design decisions. Also, all project benefits and the great majority of project costs accrue during the operation stage. (For a typical office building [7], design and construction costs are 2 percent, operating and maintenance costs are 6 percent, and salaries of occupants are 92 percent of the total life cycle cost.) AI and simulation offer great potentials for improving performance and reducing costs in the operation, diagnosis, and retrofit stages.

## PROGRAMMING

Programming derives the project's requirements and criteria from the owner's needs and aspirations for a building. For instance, what space is required for each activity, how should it relate to other spaces, what environmental control is required? Programming decisions are made with very little project specific data. For instance, during programming there is no scheme for space layout, envelope characteristics and equipment to allow for simulation of the consequences of humidity control on the operating and maintenance costs. However, KS can be developed from systematic studies of playing a similar role in selection of method, modeling, and review of results. Regulations, codes, and specifications can be modeled as KSs to assist in review of plans and specifications. Inspection and testing of materials, equipment and installations may incorporate simulation, aided by KSs, as when an emulator is used to exercise and test performance of a control system [11].

## CONSTRUCTION

Simulation plays a major role in planning site construction activities, as with construction scheduling or design of heating systems for curing concrete. KS can play a role comparable to that described for simulations in preliminary and detailed design. Automation (robotics) will come to construction, and, as in manufacturing engineering, use simulation and KS in the control systems for robots.

## OPERATION

In control of building service systems, real time simulation can guide in decisions such as: how many boilers should be used at start up depending on expected occupancy and weather? As noted above for simulations in preliminary design, detailed design, and construction, KSs can assist in selecting the simulation technique, modeling the situation and interpreting the results. In addition, KS-augmented simulations can learn from experiences, for instance improving the model parameters based on comparisons, over time, of simulation results and real experiences. KS and simulation should be extremely valuable for functionality and economy in normal service. KS and simulation should be even more valuable in extraordinary conditions, such as fire emergencies, where operators' experience and judgment may be inadequate.

## DIAGNOSIS AND RETROFIT

Diagnosis and retrofit are required when a system ceases to function properly. Simulation can assist in diagnosis by determining which property changes are consistent with observed malfunctions. KSs can assist with the strategy, simulation selection, modeling, and interpretation of results.

## RECOMMENDATIONS FOR PRACTICE, EDUCATION AND RESEARCH

AI and simulation are seen as natural partners in bringing knowledge to bear on sound decision making throughout the building process. The teamwork actually is familiar to most analysts and engineers in present practice:

- engineering standards are the paper equivalents of expert systems in our traditions of guidance for decisions by reference to the collective wisdom of a profession.
- user-friendly programs already apply programmed-in expertise to check on the soundness of the formulation of a simulation and to provide default values for many variables.

## PRACTICE

AI concepts are familiar and proven to be useful in practice. However, conscious attention to exploiting the potential benefits from advances in AI principles, methods, and tools should provide rapidly developing advances in practice. Throughout the building process, from programming on to diagnosis and retrofit of existing buildings, AI and simulation will provide improved guides to decision making.

It will be vital that decision makers maintain their individual expertise and not rely blindly on "decisions" by expert systems. Decision makers should understand what they are doing, criticize recommendations of expert systems, use them as tools but not as crutches.

## EDUCATION

Simulation methods and expert systems will be valuable themselves in education to allow simulated experience and programmed instruction to be part of formal and continuing education programs. Few engineers will need to learn to be experts in artificial intelligence, just as few need to be expert in computer science. Education can focus on the knowledge and judgment needed in the profession since manual data processing skills will have little importance and require little educational time.

## RESEARCH

Much research and development are needed to realize the potentials of AI and simulation.

- new simulation models are needed to inform early design decisions based on the limited project-specific knowledge available in programming and conceptual design stages.
- simulation models and KSs are needed to obtain good initial values for design variables during preliminary design.
- pre- and post-simulation processors are needed to guide in selection of the simulation technique and the modeling, to test the validity of the model in light of simulation results, and to focus on the significant aspects of simulation results.
- research is required to model and measure significant properties such as constructability and maintainability.
- research is needed to develop techniques to assess consistency in data, plans, and specifications.
- simulation techniques need be advanced to emulate hardware and software performance for testing and control of building systems.
- techniques need to be developed to diagnose system parameters from operating experiences for improvements of control strategies and for diagnosis of causes of failures or malfunctions.

types using simulations to ascertain the effects of various requirements and criteria on function and costs. The KS, developed using simulations, would guide programmers in decisions that are consistent with the owner's desires. This is an example of the role of simulation in AI.

## CONCEPTUAL DESIGN

Conceptual Design provides one or more sets of qualitative design decisions that define a schematic design, e.g., a one story, steel frame building with a variable air volume HVAC system. Much of the knowledge base may be shallow, simple rules based on experience, e.g., one story is most economical for retail stores in suburban strips; steel frames are economical for sites subject to differential settlement. Simulations, design studies using appropriate simulation models and automated design procedures, can provide deeper knowledge. Then KS can consider decision parameters such as life cycle costs of various types of HVAC systems as functions of climate, building type, size, and occupancy, etc. Again, there is a role for building simulation in AI.

## PRELIMINARY DESIGN

Preliminary Design provides reasonable, initial values for the design variables that are given existence by the decisions of conceptual design. Simplified, but rational, simulations often are used in preliminary design. KS can assist in preliminary design, for instance, to incorporate experts' experiences in effective sequences of preliminary design decisions, identification of the criterion most likely to control each design variable, and selection of a simulation model well suited to the specific situation.

Decisions in the programming, conceptual and preliminary design stages have significant effects on building values and costs. These decisions presently are not well supported by our most advanced simulation capabilities. The design variables called for by detailed simulation inputs are not all defined until completion of the preliminary design stage.

Two KE approaches seem possible to make simulation more effective in early design decisions. One is to formulate "default" values for design variables for detailed simulation methods using KSs that consider building occupancy, type, location, etc. The other is for KE to formulate simplified, but rational, simulation methods that require only the project-specific information available at the intended stage of use. For instance, a steady-state thermal performance model and minimum design temperature might be used for preliminary heating plant sizing. Detailed simulation studies would be used in the KE for either alternative. The choice will be a matter of efficiency and effectiveness considering factors such as clarity of decision bases and computational requirements.

in preliminary design in solving for the value of a variable that would satisfy a criterion. Fenves [8] has explored such techniques for preliminary structural design.

## DETAILED DESIGN

Detailed Design involves establishing final values for each design variable. The uses of detailed simulation methods in detailed design probably came first to our minds when we considered the roles of AI and simulation in the building process. There are important roles for KS in guiding decisions in formulating the simulation model, guiding the simulation process, and interpreting the simulation results.

- KS can emulate experts' judgments in selecting a simulation technique appropriate to a specific situation. An early, prototype KS [9] guides in modeling of structural performance with consideration of the nature of the loading and the potential mechanisms of failure.
- KS can guide in details of modeling, e.g., how many zones should be used for thermal modeling of a building.
- KS can test whether input describes a well-formed problem, e.g., are U values assigned for each envelope element.
- KS can control the stream of computation, e.g., for a numerical integration process, the step size can be selected based on the situation and the convergence rate of recent steps.
- KS can guide in analysis of simulation results to bring significant results or trends to the attention of the designer.
- KS can guide in the modification of design variables to meet performance requirements or to reduce costs. Such modifications can be based on simplified, rational simulations as described for preliminary design, or on formal optimization procedures.
- For formal optimization, KS can be used at the stages equivalent to those described above for detailed simulation.

Plans and specifications are the end products of detailed design. Presently they are produced on paper. As the information age proceeds, they may become data files. KS employing geometrical simulations can look for interferences among elements of various systems. KS can test plans for aspects such as constructability. KS can assist in formulating specifications for materials, procurement, testing, installation, etc., and testing them for completeness and consistency. SASE [10] is such an application for the synthesis, analysis, and expression of standards.

## ACCEPTANCE

Acceptance by the owner and cognizant regulatory authorities occurs in both design and construction stages. Approval of plans and specifications may be based on independent simulations, similar to those described above for detailed design with KS

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