Cognitive Modelling for the Prediction of energy-relevant Human Interaction with Buildings

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Introduction

Building occupants interact with various elements of a building in order to satisfy their diverse needs – such as thermal comfort, privacy, task implementation, etc. As a result they significantly influence the energy balance of a building. For example, operating windows has a major influence on heating demand; operating lighting has a major influence on electricity demand, etc. If energy saving is an aim, this human interaction with buildings must not be ignored.

In building sciences building simulation systems are very often used in order to predict and optimize the energy balance of newly planned buildings. Based on local weather data these codes calculate the dynamic energy flows in and around the building caused by solar radiation, temperature, and humidity differences and convective energy transport, etc. The algorithms are well established and validated.

In an attempt to reproduce human interactive behavior in buildings, various algorithms have been developed in recent years that can be used in building simulations. Usually, these algorithms are rather simple stochastic models – such as probit models – that link a (limited set of) predictor(s) – such as solar radiation – to the execution of a particular action – such as closing the sun screen. Due to their simplicity they fail to capture both, the multifaceted character of the context of interaction as well as the complex cognitive processes underlying interaction.

Research aims

A larger research project has been started in the past in order to improve the predictability of energy- relevant human interaction with buildings by means of analyzing the involved psychological processes and by developing an according cognitive model (Grabe, 2013, 2014b). This research project can roughly be subdivided into three main parts (Grabe, 2014a): The first part aimed for the systematic identification of the contextual factors and their interrelations that are relevant for this type of interaction and developed a heuristic method to achieve this goal (Grabe, 2015). An example for a typical contextual factor is the structural and mechanical characteristics of the element the occupant wishes to interact with and its reachability (e.g. the window). These factors determine the ease of use of the element and thus (part of) the costs of interaction.

To be useful for prediction, these somewhat qualitative relationships need to be transferred – in a second step – into scientific conceptualizations of pertinent disciplines. This has already partly been done by identifying a vast number of theories from psychology and social sciences that theoretically conceptualize the above mentioned qualitative relationships and that have potential to be useful for a predictive model. Among those, cognitive architectures – such as ACT-R (Anderson, 2007) – play an important role.

Finally, the third step will aim at the integration of these theories into building simulation systems. This requires a specific adaptation to the syntax and semantics of building simulation systems and the transformation into software code for the quantitative prediction of behavior.

Cognitive modelling fields

A number of psychological processes that take place prior, during and after interaction seem to be particularly suited to be modelled by the principles of cognitive architectures. An example will illustrate this point.

During interaction, a building occupant is confronted with a basic type of decision: The operation of which element of the building is best suited to satisfy his or her actual need given the actual context? Imagine a person that is feeling too warm and sets the goal to feel cooler. In principal, there is a multitude of action options to choose from: opening the window, switching off the heating, removing part of the clothing, closing the sun screen, switching on the cooling, etc. However, these action options are not equally suited to satisfy the actual need in the given context. To make a decision, further contextual information must be received directly from the environment via some sensory system (e.g. the fact that the sun is currently not shining) or must be retrieved from declarative memory (e.g. the external temperature as experienced before entering the building, or the fact that the heating is currently not switched on). Further on, each action is associated with a certain probability to be successful in satisfying the actual need and there are also costs attached to the execution of each action. Both, probability of success and costs are not easily defined. A measure of success might include how fast a temperature drop can be achieved and how sustainable the new conditions are. Costs might include diverse aspects like the physical effort to move to the window or in how far the (anticipated) new conditions will interfere with the satisfaction of other needs (for example, opening the window might increase noise level and interfere with task implementation). Moreover, satisfaction of a need might be more or less urgent (e.g. feeling hot instead of simply warm increases urgency). This urgency can be expressed as the value of achieving the particular goal.

From the perspective of cognitive architectures, it is plausible to regard these different action options as a set of potentially adequate production rules to reach the goal. Each production rule has its own specific utility, given a particular context. Determining factors such as probability of success or costs are learned during interaction with a specific building in a specific context and utilities can be established.

Relevant specificities of building simulations

Behavior cannot be analyzed or predicted without considering the physical environment in which it takes place. Building simulation systems are well suited to simulate essential parts of this environment and can thus represent the required counterpart to the simulation of particular types of behavior. However, some specificity has to be taken into account. A main example of such specificity is the simulation time span and the time discretization in building simulations. Since we are interested in the building's performance during the whole year, simulations usually comprise 8760 hours. The involved thermo-dynamic processes usually show such a low dynamic that a time discretization below 30 minutes is seldom reasonably; and even with such a discretization the amount of produced data is enormous. This is not well in agreement with the dynamic of cognitive processes which usually requires a far finer time discretization.

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