INVOCATION OF BUILDING SIMULATION TOOLS IN BUILDING DESIGN PRACTICE

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ABSTRACT

This paper reports on two case studies that explore the current use of computational tools in building design scenarios. Goal of the project is to gain insight into the role of tools in the design process and to investigate and capture the designer's viewpoint concerning building simulation. This viewpoint is essential for a successful application of simulation in the design process, but might differ from the viewpoint of the developer of simulation tools. Context of these case studies is an ongoing Ph.D.-project at Delft University of Technology that focuses on better integration of analysis tools (simulation tools in particular) in informed design strategies.

KEYWORDS

Building design practice, energy saving components, building simulation, case studies, process modeling

INTRODUCTION

Due to development and use of novel design features and due to increasing emphasis on performance aspects like energy consumption and (thermal) comfort, the need for adequate decision support during the design process is ever growing. Design decisions concerning specific parameters like U-value, airtight-ness and thermal capacity are known to have a strong impact on mentioned performance aspects. Because of the complex interaction between these design decisions and mentioned performance aspects one would expect these decisions to be based on rigorous design analysis, e.g. supported by building simulation tools.

In building research, the use of computational tools for building performance simulation is widely accepted. However, in spite of clear merits and successful demonstration projects like the IEA Task 13 low energy dwellings [1], application of these tools by building design teams has not become common accepted practice. Many research projects have aimed at bridging the gap between the world of building design and the world of building simulation, so far however without overwhelming success. Although a number of plausible causes has been found (e.g. the unavailability of appropriate models, the costs of simulation or the knowledge required to use expert tools) it has been proven to be hard to provide real solutions, hence the same problems prevail.

Development of a strategy for the use of simulation tools as an indispensable support instrument in building design is the goal of this research [2]. This strategy will be defined by a set of causal relationships between qualified design requests and deployment of pre-defined 'design evaluation experiments'. The term 'experiment' is used here in its broadest meaning. Any procedure that can be used to test the performance of a given design , be it through physical experimentation, virtual experimentation through simulation or thought experiments (engineering judgement) would qualify as a 'design evaluation experiment' in this context. In the case of simulation based experimentation, it is assumed that each experiment can be associated with an accredited set of simulation tools. Simulation runs are followed by dedicated, request specific post processing of the simulation output results. This post processing transforms the raw output data to semantic performance results in the context of the design request.

In the current stage of the research, the broad field of building design is narrowed down to a specific design domain where the role of simulation is of particular importance: the integration of energy saving components in existing building concepts. Energy saving components can be defined as integrated building components that are designed to contribute to lower energy demands. Examples of energy saving components are sun spaces, solar walls, advanced glazing systems or photo-voltaic arrays.

This paper focuses on a structured analysis of two real building design cases (real life building design scenarios) that involve the use of simulation tools.

The goal of the study is to analyze the role and points of invocation of tools in the design process and to investigate the role of the design team in the decision to request expert analysis interventions. Getting a better understanding of the design team's role is essential for a successful application of simulation in the design process: it is the design team that brings in the consultant, who in his turn can decide to use simulation tools. The study will also reveal the differences that exist between the intentions of the simulation tool developer and the ultimate client of their results (the design team).

APPROACH

Selection of cases

The design scenarios investigated have been selected based on the following requirements: (1) emphasis on the deployment of energy saving components, (2) use of simulation tools in the design process, and (3) willingness of design team and consultants to participate in the research project. Furthermore, the cases are selected from a narrow class of project types and size as to have enough similarity among them to warrant general conclusions about characteristics of the design process and design decisions. For project size large office buildings with a high energy saving profile are selected, because these are the most likely to make use of energy saving components in the final design as well as the most likely buildings to involve the use of simulation tools during the design process. For similarity in size, cases with a floor area of approximately 10.000 m^2 have been selected.

The cases will be studied with a focus on integration of energy saving components into the design, and the role tools play in this integration; the study is not concerned with studying the overall optimization of the energy performance of the building.

Two cases are discussed in this paper: the 'Rijnland Office Building' and 'ECN Building 42'. More information about these cases is given below.

'Rijnland Office', Leiden, The Netherlands

designed by Jan Brouwer Associates, The Hague, NL

This building is designed to become the headquarters of the Rijnland Regional Water Authority in Leiden. Gross floor area is 12.000 m^2, the building will accommodate +/- 300 people. The Rijnland brief asked for an environmentally conscious building; this has resulted in a number of energy saving measures, including use of energy saving components (long term energy storage in the soil, heat pumps, low-temperature heating, high temperature cooling, heat exchangers, climate facade, daylighting systems, atrium), as well as in careful selection of building materials and a rainwater reuse system. The building is currently under construction and is expected to be completed in November 1999.

The project has been granted the status of 'exemplary project' in the field of energy-conscious and 'sustainable' building by the Dutch government through SEV (Steering Committee for Experiments in Public Housing) and NOVEM (Netherlands Agency for Energy and the Environment).

figure 2: Rijnland Office
(courtesy of Jan Brouwer Associates)

'ECN Building 42', Petten, The Netherlands

designed by BEAR Architects, Gouda, NL

Building 42 is a new adaptable building for the Netherlands Energy Research Foundation ECN, which will be built to increase office and laboratory space available. According to ECN's mission, the new building will 'contribute to a clean and reliable energy supply for a viable world'. Building 42 consists of three identical units, that are connected by a large conservatory; the conservatory also connects to the existing Building 31. Gross floor area of Building 42 will be about 9.000 m^2. The three units will be built in three phases during 1999-2009, depending on demands.

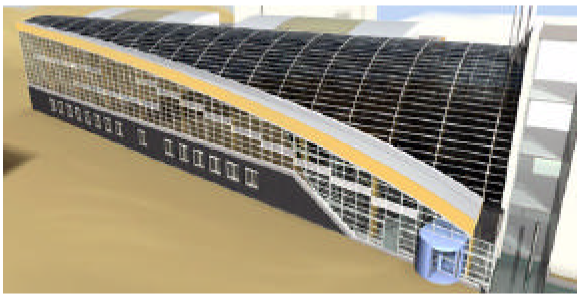

figure 3: ECN Building 42
(courtesy of BEAR Architects / M.Art)

The following energy saving components have been integrated into the design of Building 42: photovoltaic arrays, conservatory, daylighting system, atria, co-generation unit, heat exchanger, nocturnal ventilation cooling system in summer. Construction of the first part of Building 42 starts on April 1st, 1999.

Analysis of cases

Each case is analyzed using the following approach [3]:

1. Data gathering phase

Phase one consists of collecting relevant information about the case. Literature concerning the case is reviewed. Participating companies, key actors within these companies, their disciplines and the teams and structures in which they operate are identified and laid down. Special attention is paid to communication patterns and reports of team-meetings. Finally the most important participants in the design process - the architect and the simulation expert - are interviewed. Decision moments, concerning energy saving components, with or without the intervention of expert analysis, whether supported by the use of tools or not, are analyzed in depth.

2. Process modeling phase

Phase two consists of a structured analysis of the data collected in phase one. The design process of the case, including building simulation procedures, is represented formally by means of process diagrams according to the IDEF-0 (Integral Definition) process-modeling method [3, 4]. IDEF-0 models are designed to help promote good communication about processes, and are designed to help the process analyst in identifying what functions are performed by the process, what is needed to perform those functions, what the process does right and what the process does wrong.

IDEF-0 models represent a process as a series of diagrams. In these diagrams the activities that make up the process are depicted as boxes. Interfaces between the activities are depicted as lines with arrows that either enter or exit an activity box. Four kinds of interfaces (called 'concepts' in IDEF-0) are distinguished:

inputs:	information or objects required to perform the activity;
outputs:	information or objects that are created when the function is performed;
controls:	the conditions or circumstances that govern the activity's performance;
mechanisms:	the persons or devices that carry out the activity.

Inputs enter activities from the left, controls from the top, mechanisms from the bottom. Outputs leave activities on the right. See figure 1.

IDEF-0 uses a hierarchy of diagrams. One top-level diagram (A0) shows the process as one activity only; this activity is broken down (decomposed) into more detailed diagrams (A1, A2, …) that can themselves be decomposed until the tasks are described at a level necessary to support the goal of the process model.

For an efficient implementation of IDEF-0 the KBSI function modeling tool AI0-WIN has been used [5].

Clearly the main focusing point within the final process diagrams should be the use of simulation tools within the design process.

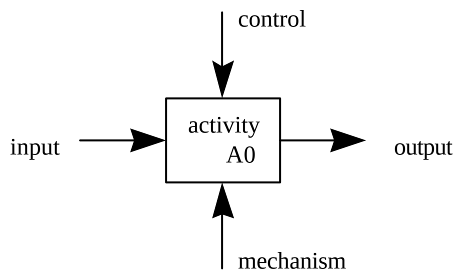

figure 1: IDEF-0 representation of concepts and activities

3. Feedback interaction phase

In phase three the key actors (process experts in 'design' and 'simulation') consulted in phase one are asked to review the process diagrams resulting from phase two. A second interview is used to provide feedback and correct errors or oversights that might be present in the diagrams. At this stage, possibilities for improvement of the design process with regard to the use of building simulation procedures are discussed as well.

RESULTS

Case study 'Rijnland Office'

For the design process of the Rijnland Office, diagram 1 shows the key actors and the roles of these key actors.

The design team consists of the architect and the consultant for installations (both supported by staff of their own company). Within the design team, the architect is in control of all decisions. The architect also is the pivot in the whole team.

The design team develops design proposals, which are presented to the principal; the principal either accepts or rejects these proposals, and hence controls the design team.

Both design team members use consultants to carry out specific tasks (evaluation or information gathering) upon request; these consultants might once more pass on part of the task to subcontractors.

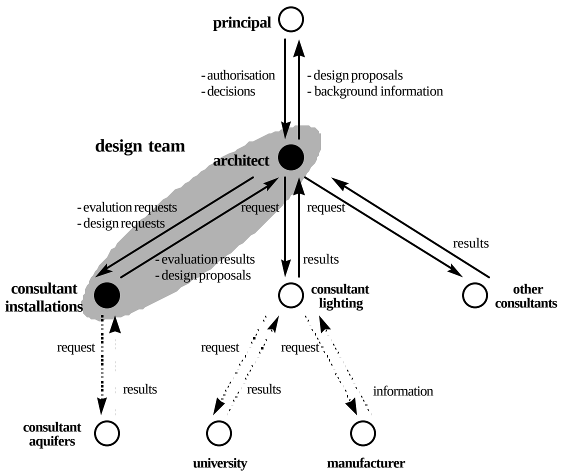

diagram 1: Key actors and roles in the design process of the Rijnland Office.

The design process of the Rijnland Office has been analyzed using IDEF-0 diagrams. Five main phases have been distinguished: 1. feasibility study; 2. conceptual design; 3. preliminary design; 4. final design and 5. preparation for building construction. During the first phase the architect studied the feasibility of the project and drew up his team. In the phase of ‘conceptual design’ the architect developed the project strategy, and in collaboration with the consultant for installations developed the outline design. In the phases of ‘preliminary design’, ‘final design’ and ‘preparation for building construction’ the outline design was refined; however, no fundamental changes were made.

Concerning the design process as a whole the following observations have been made:

1. The consultant for building physics and installations joined the design team very early. This implies that this team had the ability to support design decisions concerning energy saving components by simulations or computations almost from the beginning.
2. Most of the energy saving components that appear in the final Rijnland design were introduced very early, and where introduced together with the building outline.
3. Only one energy saving component has been introduced to the project and has been rejected in a later phase: the use of translucent insulation material (TIM) in the daylighting zone of the facade.
4. Most of the consultants’ work seems to have consisted of suggesting new systems, or fine-tuning systems that already were a fixed part of the design. There is very little evidence of consultant ’informing’ the choice between different design options by offering analysis based on calculations or simulations. In other words: computations were mostly used to confirm assumptions, not to make decisions. In this respect the lack of tools in diagram 2 is illustrative.

The architect expressed his concerns about the procedure of computing the effectiveness of the design in a later stage. However, time constraints as well as the fact that the computations had to be made by others made another approach impossible.

One characteristic decomposition diagram, which describes the phase of ‘conceptual design’, is shown in diagram 2. This phase is most important because:

- almost all ideas on building outline, as well as ideas on the use of energy saving components, where introduced at *one specific moment only;* strangely this one phase where the design suddenly emerges is called ‘study of aspects’, rather than ‘design’.
- the project strategy, developed by the architect, depends largely on the reference projects Amsterdam Airport Schiphol, Zwitserleven Office and buildings for IKEA (and hence on experience); there is a lack of an universal design strategy.
- the brief, which is the yardstick for the building design, is changed alongside with the development of the design.
- information about the existence of the feedback loop was unclear: the feedback was only mentioned by the consultant. However, the consultant agreed that the feedback did *not* influence the design. Yet this feedback loop is the link in the design process where computational results could have the most influence on the building design (provided the consultant uses tools in this phase, which he didn’t).

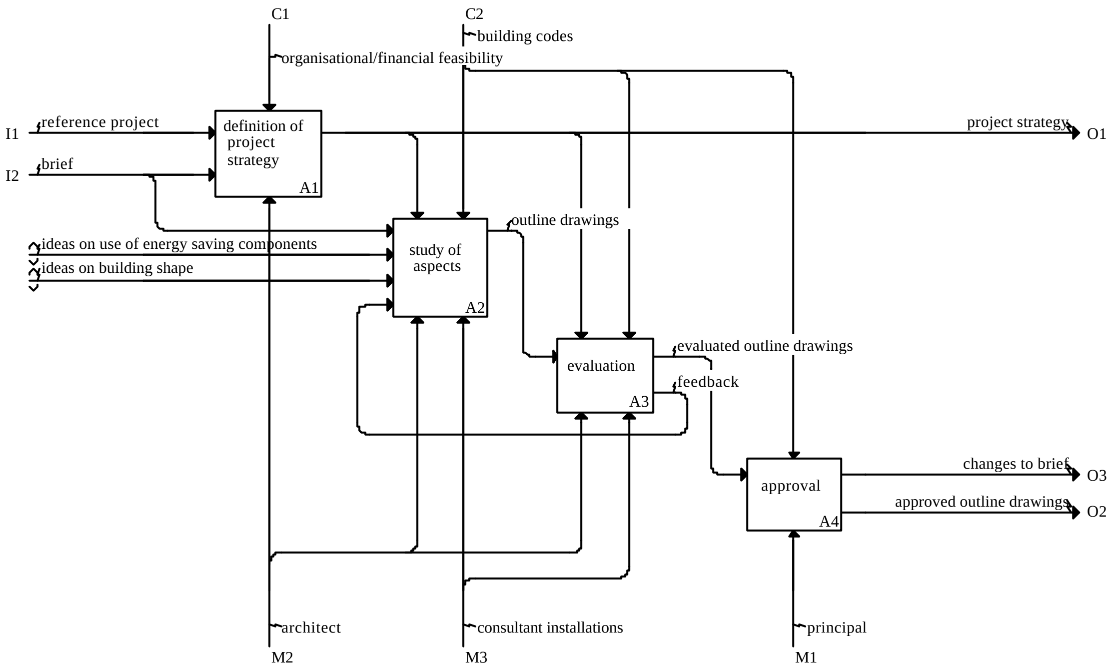

Diagram 2: IDEF-0 diagram describing the phase of conceptual design (Rijnland Office)

Case study 'ECN Building 42'

Diagram 3 shows the key actors and their roles in the design process of ECN Building 42. See diagram 3.

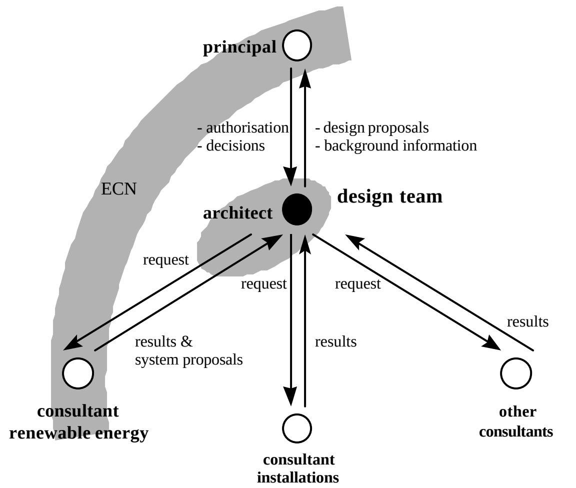

diagram 3: Companies, key actors and their roles for the design of ECN Building 42.

In this case the design team consists of only the architect. The consultant for renewable energy provided some system proposals, but this happened on an informal basis and not upon request. Again, the architect was backed by a team from his own company.

The position of the principal and consultant for renewable energy in this case are very special: both are part of the same company. This resulted in a close cooperation between principal, architect and consultant for renewable energy. However, competencies where strictly separated: the principal made the decisions, the consultant only supplied evaluation results.

The design process of the ECN Building 42 has been analyzed using IDEF-0 diagrams. Six main phases have been identified: 1. preparation of the brief; 2. feasibility study; 3. conceptual design, 4. preliminary design; 5. final design and 6. preparation of building specifications and construction drawings. During 'preparation of the brief' the only actors were the two divisions of ECN that were later to become principal and consultant for renewable energy. Very important in phase one was the decision to employ an architect - in the past, all new buildings for ECN were developed by ECN divisions. In the phase of the 'feasibility study' the architect was introduced, and took over the role of coordinating the design process. In the phase of 'conceptual design' the architect studied the brief; during this study a series of building concepts emerged, together with the idea of integrating a number of energy saving components. One concept was selected and resulted in outline drawings, which were approved by the principal. During the phases of 'preliminary design', 'final design' and 'preparation of building specifications and construction drawings' these outline drawings were refined. The consultants for renewable energy and for installations carried out a number of simulations. The results from these simulations were used for system dimensions, as well as for confirmation of expectations about performance of the design. However, the simulation results did not cause any fundamental changes in building design.

Concerning the design process as a whole the following observations have been made:

1. In this particular instance the consultant for ‘renewable energy’ is a close affiliate of the principal. Energy performance is an up-front and essential part of the project that is given attention from the very beginning. In this case computational / simulation tools are available during the whole design process.
2. For the site of Building 42 very strict regulations apply, because the owner of the land is the Dutch National Forestry Service. These regulations dictate the coordinate system for the plan, and hence (solar) orientation.
3. In this project, again energy saving components are introduced in an early stage: i.e. during the conceptual design. It must be noted that this early phase of the design is mostly concerned with providing potentially applicable components, rather than testing the effectiveness of these components. Evaluation of ideas is carried out through visits of similar projects in which these components have been used and is not based on simulation.
4. The architect and consultant for ‘renewable energy’ make their decisions concerning integration of energy saving components in the design based on knowledge from earlier projects/experiences.
5. Computational tools are used to check weather expectations concerning energy consumption will be met: the mandatory Energy Performance Coefficient ‘EPC’ is calculated using a prescribed tool; also TRNSYS is being used. However, it is remarkable that the results of these computations seem to have had very little effect on the overall design. In other words: there is almost no structured invocation of design analysis to collect feedback from such analyses to informed design decisions. See diagram 4.

One characteristic decomposition level of the diagram, which describes the activity of ‘preliminary design’, is shown in diagram 4. This diagram is typical for the use of tools in the design of Building 42:

- it is the architect who develops the building design and who determines the margins for input from the consultants (e.g. margins for installation design).
- the consultant for installations uses simulation tools (VABI) to determine the dimensions of the installation; these tools are *not* used to decide between different options in installation design.
- simulation tools are used to check whether the building performance meets with expectations; again, the tools are *not* used to decide between different building design options. Simulation results only have a moderate influence on the design - as input for the next design phase.

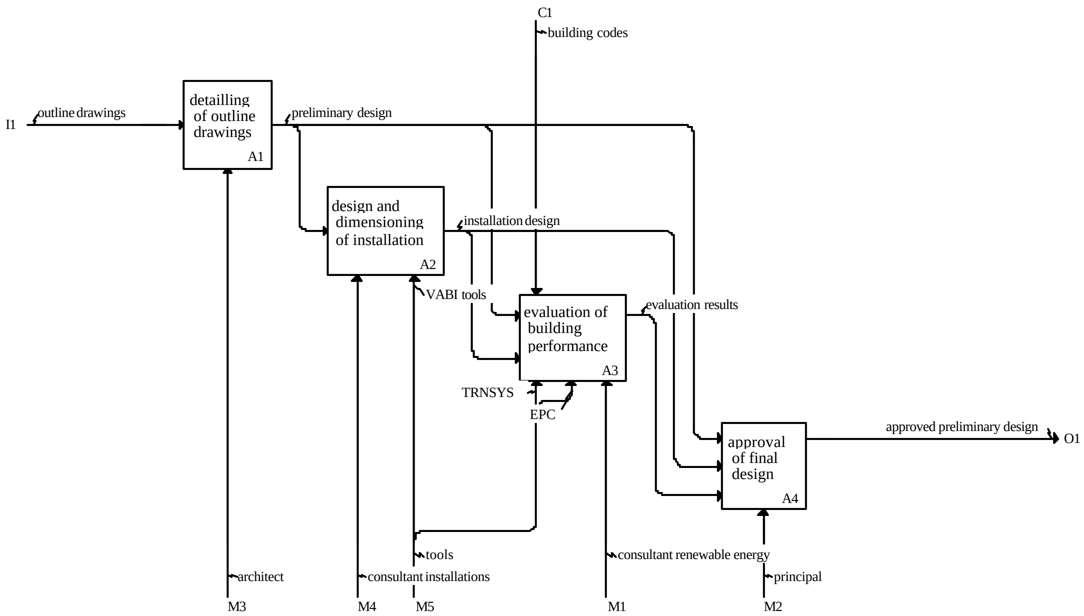

Diagram 4: IDEF-0 diagram describing the phase of preliminary design of ECN Building 42.

CONCLUSIONS AND REMARKS

1. In the two cases studied thus far, the role of computational tools has been mostly limited to confirming expectancies concerning energy consumption. The only noticeable impact of computational results on the design (including the use of energy saving components) appears to be limited to fine-tuning of systems.
2. In both cases simulation tools have been invoked during the phase of preliminary design. Tools are also used in the phase of final design, and in the phase of preparation of the building construction.
3. Both building concepts emerged in the phase of conceptual design. Decisions concerning integration of energy saving components were made in this early phase, too. In this phase decisions were based on experience and reference projects, *not* on the use of simulation tools.
4. Surprisingly, almost all energy saving components were introduced as one 'batch'. There was no consecutive integration of components into an existing building scheme. Neither there was computational support for the addition of each new energy saving component.
5. For both here discussed cases the designer's viewpoint concerning building simulation is that computational support is needed in the early phase in which the building concept emerges. However, in this phase computational support fails to materialize.
6. In the world of tool development, it is often assumed that special 'early design tools' are needed for early design phases. However, research by Robinson [6] reports that these tools are used in the same phases as more sophisticated tools. Apparently existing tools do not comply with the requirements of the design phase in which support is most needed.
7. The moment of invocation of the consultant is influenced by the architect, who is in control of the design process. The reason for invocation of the consultant is not to support and inform a design request but rather to check code compliance and dimensioning certain components. The use of simulation tools in the design process is solely at the discretion of the consultant who uses these tools.

The overall conclusion from the work so far is that there is a general misconception that the present tools respond to a well defined need of building teams. Surprisingly, (energy) simulation plays a very limited role in the average application of advanced energy saving technology. At this stage of the research the main reasons are found to be (1) a severe lack of control over when and how a particular analysis should be commissioned in order to take maximum benefit for the immediate design decision, and (2) the lack of context specific analysis scenarios, based on tools that can respond to a specific design request.
These conclusions lead to some sobriety when it comes to making grossly exaggerated claims about the energy savings that have been brought about by the present generation of analysis tools. Rather, the conclusion seems to present itself that energy conservation is a matter of 'choice' rather than 'design', and the catalyst is not simulation but motivation.

FUTURE WORK

Future work will have to confirm whether conclusions from these two cases are universally valid. This will be attained through the study of a couple of other cases, as well as specific questions for a larger group of design process experts. More general conclusions will then be supported by a process model which describes the generic aspects of the current use of simulation tools in building design ('AS-IS' model).
The next phase then addresses the main objective of the research: the definition of optimum analysis interaction moments in a (partly) redefined ('TO-BE') process model. This model will be constructed and analyzed with the help of practitioners. Its main purpose is to study the suitability of current tools to support this improved design process, or generate a requirement specification of how next generation tools should adapt and respond to the defined interaction contexts.

During this stage of the research where the focus is on task analysis, the IDEF-0 models are suitable. The 'TO-BE' model will focus on the following aspects:

- Invocation of certain analysis requests and their support by simulation during the creation of the building concept;
- consideration of each design intervention separately (possibly in a preferential sequence);
- introduction of explicit design evaluation requests for each design intervention, in order to warrant that simulation tools are invoked at the correct moment;
- design decisions based on evaluation results.

The assessment of the suitability of current computational tools for use in the 'TO-BE' model will be based on the most important design evaluation requests (concerning energy saving components) in the re-engineered cases. A set of tools representative for the different categories of tools currently in existence will be put to the test. Evaluation of the performance of the tools in these tests will be carried out using criteria relating to both building simulation (accuracy of computational results, computation time, number of inputs, etc.) as well as building design (appropriate evaluation capabilities, unambiguous results, guidance for subsequent design steps, etc.). The results of this study will be used in the reverse direction: to match categories of tools and categories of building models within these tools to specific design evaluation requests, as part of the strategy that is the final goal of the Ph.D.-project.

ACKNOWLEDGEMENTS

The authors wish to thank Jan Brouwer and Migiel van der Palen of Brouwer Associates, The Hague, Ron van der Plas of Halmos Consultants, The Hague, Henk Kaan and Frans Ligthart of ECN Solar and Wind Energy, Petten and Tjerk Reijenga of BEAR Architects, Gouda, for their kind assistance with the case studies.

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