

THINK DESIGNERLY! USING MULTIPLE SIMULATION TOOLS TO SOLVE ARCHITECTURAL DILEMMAS

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ABSTRACT

This paper aims to describe and exemplify the developed concept of 'designerly' ways of simulation. Despite the relevance of architectural decisions on thermal and energy performance, the design support frequently relies on qualitative information, which sometimes can be inadequate to specific design situations. Simulation can enhance the quality of the design support, but its influence on architectural practice is still limited. Designerly ways of simulation should combine the power of analysis (from the tools) with the power of synthesis (from designers) to allow the solution of design dilemmas that can arise during the design process.

INTRODUCTION

Despite the recognized impact of architectural decisions on the thermal and energy performance of buildings, some of the most influential design definitions are frequently based on qualitative information (Pedrini, 2003), such as general principles or precedent designs. Even though this type of information can offer guidance to tackle some design decisions, it can also hinder higher performance ambitions.

Besides, the lack of quantitative analysis can lead to errors if the information is misleading. General principles are normally vague and, thus, can be inadequate to describe specific design situations. Precedent solutions can also have hidden errors that can be transferred to future designs, leading the designer to make conceptual errors (Bay, 2001).

Simulation methods can certainly improve the quality of design support. The interfaces of simulation programs are evolving rapidly. The processes of geometrical modelling, navigation and input of data are becoming more intuitive in recent tools.

However, the use of simulation tools as part of the design process comes up against the lack of methods that are more related to the way architects proceed. Simulation procedures are frequently carried out by consultants in later design stages, when most influential architectural decisions were already taken.

Morbitzer (2003) developed a method in order to tackle the use of energy simulation throughout the design process. For this purpose, Morbitzer

developed new interfaces for the tool used (ESP-r) and investigated how the tool could be used in different design stages. A 3-stepped design process was proposed and, for each phase, a group of design tasks that could be approached.

Indeed, the method allows the quantification of several variables during the design process. However, it seems to be more appropriate to be used by consultants, given the limited relation with how architects formulate design problems.

In order to provide a theoretical framework that can facilitate the use of multiple thermal simulation tools as part of the architectural conceptual process, this paper aims to describe the concept of designerly simulation, providing examples of the practical implementation of the concept.

DESIGNERLY WAYS OF SIMULATION

The term 'designerly' was created by Nigel Cross in the late 70s. Cross (2006) asserts that design activities require a type of knowledge that is different from the knowledge used to produce art and science, which was defined as '*Designerly ways of knowing*'

Analogously, we presume that simulation methods carried out by architects as part of the design practice should have unique features in comparison to procedures commonly used by consultants. The effective integration between architectural conception and simulation methods is hard to obtain when assessments are made by consultancy firms. This is because there are substantial differences between how design problems and scientific problems are formulated and solved.

We presume that the impact of simulation on the architectural expression would be higher if architects could reproduce and simulate their own questions, while consultants could approach more technical and complex problems.

Assessment types and tools

The development of the designerly simulation concept is intended to provide support to design decisions that have influence on aspects related to the thermal performance of the building (indoor climate, heat flows, air flows and energy consumption). The proposition took into account three types of tools: solar, thermal and CFD tools.

The tools selected must be, to some extent, friendly to architects. It is worthy to mention that the purpose of the research is not to analyze how each tool works in comparison to each other. Therefore, we selected a small group of tools that had affordable student licenses and friendly operability. The following tools were selected to cover the three assessment types defined:

- Autodesk ECOTECH Analysis 2011 (solar analysis): the tool offers a great diversity of outputs and visualisation of results. The interface is legible and despite some limitations of the modelling features, it has indirect interoperability with SketchUp. The tool is used in the research only for solar and radiation analyses.
- DesignBuilder (thermal and CFD analyses): the tool has excellent modelling features, clear navigation panel and legible sequence of input data. Early design simulations can be done using the parametric features and templates.
- IES-VE (solar, thermal and CFD analyses): the tool has limited modelling features but a fairly stable interoperability with other programs. The interface and output visualization are clear, but manipulating and editing geometries within the program can be quite a counter intuitive process for architects.

Despite the limited sample of tools, we believe that the proposed concept of designerly simulation can be extended to several tools that were not used to develop the concept, as the information used in the modelling process is similar.

Objectives and related definitions

The development of designerly ways of simulating requires a basic understanding about why and in which situations should architects use simulation tools.

Most architects never use simulation tools or quantitative methods (Bay, 2001). When they do, we observe that their first contact with simulation is to tackle research tasks as part of post-graduate studies. As researchers, their approach is to investigate thoroughly a given research problem. Simulation is used to quantify the influence of a pre-defined set of variables, allowing the researchers to draw conclusions based on the results.

Our experience with simulation training courses for architects-researchers allowed us to identify some patterns. We noticed that architects tend to adopt the same scientific rigour required in the academic field when they try to use simulation during design. As a consequence, simulation assessments are restricted to advanced design stages, when they can be sure that the model accurately represents their design. However, simulation results have limited impact on the decision making process and have the sole purpose of confirming an expected performance.

The rhetorical procedure described neglects the potential of simulation tools to help architects to solve their own doubts.

The main objective of the designerly simulation concept is to solve design dilemmas identified during the design process. Design dilemmas are crucial doubts that have implications on the building performance. These doubts can arise during the design process and require quantitative analysis to be effectively solved.

Design dilemmas are resultant from the designer's own reflection process about specific design definitions. However, explorative simulation procedures can allow the designer to find design dilemmas that could not be identified otherwise. This can happen, for instance, when a given phenomena (e.g. specific heat flows) was not expected by the designer but could be noticed based on simulation results. Similarly, the solution of a dilemma can lead to new dilemmas regarding other design aspects.

According to the proposed definition, design dilemmas cannot be solved based solely on qualitative knowledge, as many design decisions can. The number of dilemmas in a given design process depends on the following aspects:

- The architect's skill to find dilemmas: in order to identify dilemmas, architects need to reflect upon design decisions and have a background knowledge to formulate questions about them. Designers who neglect performance implications and lack the basic knowledge to deal with these questionings would never have dilemmas.
- The design ambitions: design processes with high performance ambitions tend to generate more dilemmas because performance criteria are inherently related with the fundamental goals.

For each type of assessment considered, groups of inter-related design decisions were identified to define the general scope of dilemmas that can be tackled (Figure 1).

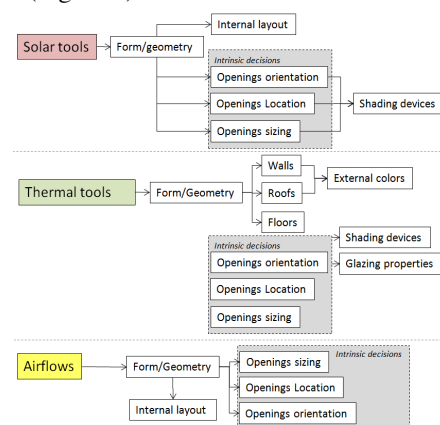


Figure 1 Scope of architectural design decisions regarding thermal and energy performance.

These decisions are intrinsically related to the architectural design practice and can have a

considerable influence on performance. Even though the decisions are quite broad and general, the design dilemmas related to them can be very specific. Dilemmas can focus on specific properties (eg. color, dimensions, R-value, etc) or on elements and strategies that combine sets of properties (eg. wind collectors, shading devices, glazing systems, etc). Given the number of combinations, it would be virtually impossible to name all the possible dilemmas. Besides, dilemmas are closely related to the specificities of each design situation (and how it is approached by different architects).

The nature of design problems

Design dilemmas are shaped by the knowledge and criteria that are used to formulate a given design problem. Design problems are considerably different from scientific problems, especially because they involve knowledge and information that are not mentioned in the design brief (Lawson, 2004).

This is evident in design competitions, when architects receive the same requirement but produce different results. This is not only related to discrepancies in skill, talent or professional competence (Harfield, 2006). According to the argument proposed by Steve Harfield, there are not *'fifty solutions for the same problem, but (...) fifty solutions to fifty different problems'*.

Harfield (2006) states that architects do not react impartially to the problem *as given*. Each designer approaches design problems with their own *'likes and needs, assumptions and beliefs, preferences, prejudices and biases, knowledge, skills and understandings'*. These personal attributes are used to determine what is considered an interesting design problem and set parameters for acceptable solutions.

In the professional practice, differently from design competitions, design problems are defined by more constraints. They can be generated by the following agents: the designer, clients, users and legislators (Lawson, 2006). The constraints generated by each of these categories can affect several aspects of the design and have different levels of flexibility.

Due to the ill-defined nature of the design problem, the definition of design solutions is made according to a solution-based approach, in contrast to the scientific problem-based approach (Cross, 2006).

As part of solution-based strategies, architects use principles and precedent solutions from other architects as references. This knowledge, essentially qualitative, works as 'shortcuts' to allow architects to take decisions without dealing with the *'combinatorial explosion'* of possible alternatives (Bay, 2001). However, without quantitative evaluations, such information can be misleading.

Description of designerly ways of simulation

The proposition of designerly simulation should combine the power of analysis from simulation tools with the power of synthesis from architects.

This means that processes and information inherently related to the architectural conceptual process should be used as part of the simulation procedure, which results in a closer relation with how the design problem is formulated and solved. Therefore, design dilemmas – and the simulation model – can be defined and constrained by design conjectures, concepts and intentions.

The development of the concept took into account the following assumptions:

- Science and design: we presume that simulation to provide design support can be less rigorous in comparison to scientific research as several design features are unknown or partially defined. The main purpose of solving dilemmas is to compare design alternatives. Such analysis does not need to be related to performance parameters extracted from real buildings, but allow the designer to compare solutions. The model can have several abstractions in terms of geometry, schedules and HVAC systems and still provide useful and comparable results. The uncertainty in design support can be higher in most situations because other criteria besides performance also influence the decision.
- Design dilemmas: the focus of simulation is to solve design dilemmas. A dilemma should be formulated using pragmatic constraints (generated by the designer, clients, users and legislators) and abstract constraints (mostly generated by the designer and clients). A constraint is more pragmatic when its related features can be directly input in the software. Abstract constraints, on the other hand, need to be processed by the designer to become inputs.
- Shortcuts: the formulation of design dilemmas can be influenced by qualitative information such as design principles and precedent solutions. Such information can be used to generate design hypothesis or to reduce the scope of a dilemma.

The designerly simulation process is represented in the Figure 2. The diagram shows the timeline of a design process. Throughout the timeline, the design evolves as new design features are defined, and more design definitions are available.

Whenever a dilemma arises (represented by '?') the known features of the design are used in the simulation model. While some of these features can be fully defined, some information can be partially defined or even completely unknown.

The simulation model that represents an incomplete design should prioritize information that is related with the given dilemma and the type of assessment. Solar and CFD assessments, for instance, require more geometrical definitions, whereas thermal and energy assessments require information about the properties of building elements, occupation and

systems. Depending on the type of assessment, available information can be ignored (gray bullets) or used as inputs (red bullets) in the simulation model.

Simplified simulations involve abstractions or even the stipulation of unknown information. The level of simplification depends on the specific dilemma and the stage of design development. A dilemma would not be pertinent if relevant design definitions, directly related to the dilemma, are unavailable. For instance, the quantification of the insulation impact on heating loads should be compromised if the geometry of the building is completely unknown.

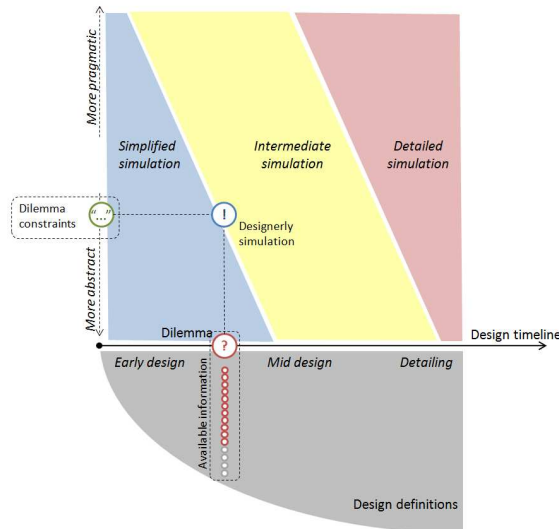


Figure 2 Representation of designerly simulation.

The simulation of a design dilemma should adopt information that is used in the formulation of design problems. This information is strictly related to design constraints (Lawson, 2006) that can be pragmatic or abstract (Figure 2). Both types of dilemma constraints are intended to reduce the scope of the analysis.

Information generated by pragmatic constraints is easier to implement in simulation models as it can be directly input in the model.

The use of abstract constraints, on the other hand, is indirectly transferred to the model. This information should be processed by the designer and translated to be used in the model. Some examples of this translation process can be mentioned:

- Cost constraints related to a given dilemma allows the elimination of solutions that would be too expensive. In a similar way, the definition of performance goals or design ambitions can lead to a range of acceptable solutions.
- An abstract conjecture, concept or design intention, such as 'transparency', for instance, can generate pragmatic inputs. A 'transparent' wall would have a high WWR (window-to-wall-ratio). Similarly, the design of shading devices according to the premise of 'transparency' would have to implement specific features. This

concept would, as a consequence, eliminate solutions that block the visual contact between exterior and interior spaces.

Even though the process of transforming abstract constraints into pragmatic inputs is complex to describe or fully represent, similar techniques are widely used in architectural design. Architects intuitively deal with several conjectures in order to formulate problems and identify parameters for acceptable solutions.

During this process, designers can use information as 'shortcuts' to facilitate the translation of abstract constraints. In design practice, this information is often related to previous experiences of the architect and is rarely based on quantitative criteria.

In designerly simulation, information used as a 'shortcut' should allow the identification of some inputs. The concern of using misleading precedents is minimized as they can improve using simulation. Two types of information are approached:

- Design principles: the use of guidelines can reduce considerably the scope of analysis. Such information can be used to focus on specific design strategies.
- Precedent solutions: the analogy with specific features extracted from precedent solutions can be useful in the process of transforming abstract intentions into pragmatic definitions.

The process of transferring information from these sources to the model depends highly on what is intended by the designer and how the information used as a 'shortcut' represents the intention.

Of course, the process of designerly simulation has a strong human component. This is clearly related to cognitive processes and assumptions that are an inherent part of any design activity.

EXAMPLES OF DESIGN DILEMMAS

The proposed concept was used to tackle design dilemmas extracted from different case studies. In this paper, we present two examples of dilemmas that were investigated using simulation tools.

The case studies presented are more influenced by pragmatic constraints, as both have high performance goals. Processes with more abstract constraints should be approached in future works.

Example 1: residence in Zwolle, the Netherlands

The first case study was an ongoing design with high performance goals. The residence, located in Zwolle, the Netherlands, was intended to generate its own energy using PV panels connected to a smart grid and solar collectors for water heating.

The leading architect Jamie van Lede (Origins architecten, Rotterdam) was interested in using simulation methods to support the design development. Firstly, simulation tools were used to answer general questions from the design team

regarding the influence of building elements. The explorative investigation, which is not presented here, is similar to a consultancy process. The designerly concept was applied in punctual situations identified and constrained by the researcher.

The practical application of the concept in the first case study is highly hypothetical in the sense that we did not have access to all criteria, preferences and concepts generated by the designer and by the clients. Indeed, this would require a closer integration with the design team. Besides, in order to create design dilemmas, the designers should be aware of the concepts presented here.

The design was in intermediate stages of development when we tackled the first dilemma. The internal layout and geometry of the building were fairly defined (Figure 3), which allowed a more precise geometrical modelling. Some of the building elements, such as walls, roofs, floors and glazing systems were not fully known, but ranges of possibilities with extreme performances (minimum and maximum) were provided by the design team.

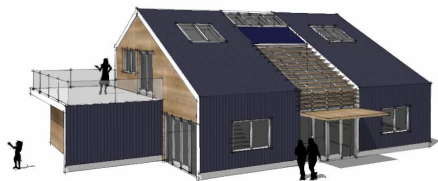


Figure 3 Model of the residence (early design stage)

The simulation process to tackle the dilemma presented can be described by the following aspects:

- Goals: improve the performance of the best case scenario (according to the ranges of options provided by the design team). The reference case adopted combines high performance insulation in walls, roofs, floors, glazing systems and low infiltration rates. Simulation should be used to investigate possibilities to increase solar gains during the winter, reducing heating loads. A trombe wall can be a suitable solution as it has three layers to maximize solar gains and heat storage: an external glazed surface, an air cavity and a black painted high thermal mass wall.
- Dilemma: what would be the impact of an uninsulated trombe wall?
- Pragmatic constraints: information extracted from general guidelines was used as a shortcut to define the properties of proposed trombe wall.
- Abstract constraints: a trombe wall would have some aesthetical implications and drawbacks in terms of space quality, as two south oriented windows are relocated. Given the fact that this information was not available, performance criteria are prioritized over these constraints.

The DesignBuilder software (Designbuilder, 2000-2010) was chosen because of its modelling features.

The occupancy and system inputs were imported from templates, based on specific literature (Department of Energy, 2009) or provided by the design team.

Given the high performance goals, the reference model is the best case scenario at the particular stage of design development. The following properties were used in the model (Figure 4):

- R Walls/Roofs = 6.4 m²K/W.
- Ground floor R=5 m²K/W.
- Glazing U = 0.8 W/m²K; SHGC = 50%.
- Infiltration rate = 0.3 ACH.
- Underfloor heating (heating set point = 18°C).

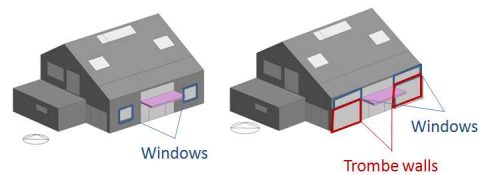


Figure 4 Geometry of the simulated cases (mid-design stage).

In order to identify the pertinence of the strategy (trombe wall), the elements of the trombe walls have a relatively low performance. If the benefits are confirmed and the design team is interested in making further investigations, several elements of the trombe walls can be enhanced, and the benefits increased. The following features were used:

- Air cavity of 20cm.
- Uninsulated concrete wall painted in black.
- Low-E Double Glazing (U=1.2W/m²K; SHGC=53%).
- No vents to maximize convective gains.
- No summer shading (the focus at this moment is to reduce heating loads).

Simulation results indicate a reduction of 13% on heating loads. The benefits are considerable, considering that i) the design already has a high performance and ii) the trombe walls can be improved in later stages.

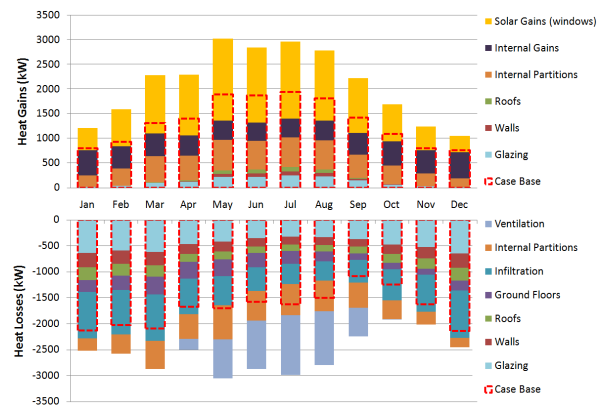


Figure 5 Monthly thermal balance

The analysis of monthly thermal balance (Figure 5) indicates that the heating gains during the coldest months increased 30% in average, whereas heat losses increased 17% (the case base is represented by the red dashed contours).

Heating gains during the summer also increased considerably, which highlights the need of operable shading devices to block solar radiation during the hottest months.

In order to get more information about the performance of the trombe walls, temperature oscillations were analyzed (Figure 6). The winter typical week (3/2 until 9/2) and winter design week (10/2 until 16/2) were selected. Each week presents different scenarios in terms of solar exposure.

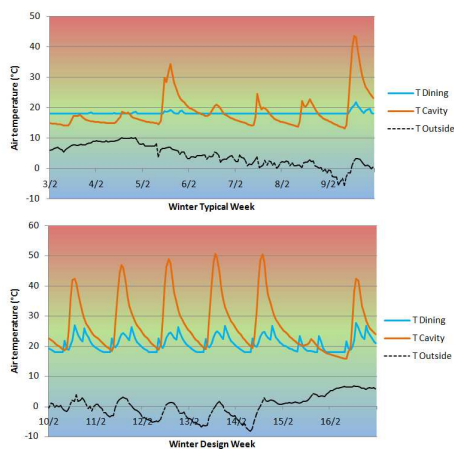


Figure 6 Temperature oscillations during representative winter weeks.

The following points can be observed:

- When solar gains are low, the temperatures in the cavity can get down to 11°C.
- When solar gains are higher, temperatures in the cavity are considerably high (up to 50°C), even when external temperatures are as low as 2°C.

Results indicate that the strategy is pertinent to be further investigated along the process. The trombe wall can be improved in terms of insulation, summer shading, efficient glazing and vents.

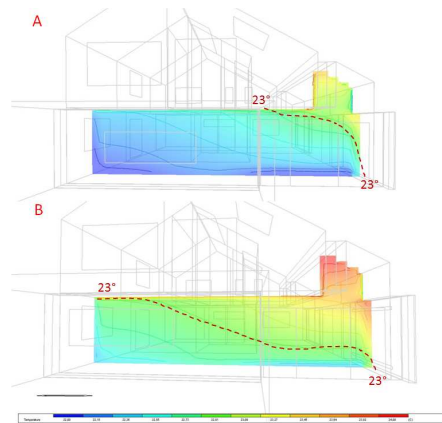


Figure 7 Temperature distribution without vents (A) and with vents (B).

The use of vents to maximize convective gains was approached as a complementary dilemma. In order to identify the impact on temperature distribution, a CFD calculation was made using the same model. The boundary conditions of the day 13/2 at 18:00 were imported from EnergyPlus results (Figure 7).

The results indicate that the temperature distribution is much more uniform in the improved case (results use the same colour scale from 22°C to 24°C).

Example 2: energy-neutral house in Amsterdam

Unlike the previous example, the second case study was based on a finished design process. This method allows a better understanding about the design evolution.

The information about the process was obtained through an interview with the leading architect and complemented by the visual information provided. The intention of the investigation is to allow the reproduction of different stages of design development. With the available information and constraints at specific moments, we should tackle identified dilemmas using simulation tools.

The energy-neutral house was designed by the architect Pieter Weijnen (FARO architecten) for himself and his family. The design process was highly affected by his previous house, known as the 'blue house' (Figure 8).

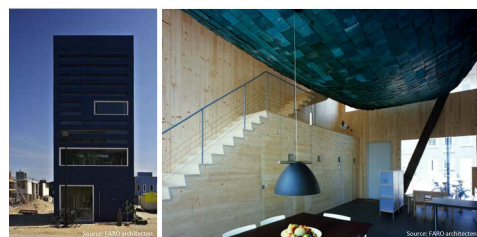


Figure 8 The 'blue house' (source: FARO architecten)

In the first house, the designer implemented high efficiency systems and used recycled materials. However, the designer admitted that the architectural envelope was only standard in terms of performance.

The opportunity of building a second house in the same neighbourhood allowed the architect to improve considerably some aspects of the first house. Performance requirements were strongly prioritized, and the design process had the support of a consultancy firm. Some design information can be highlighted:

- Similar conditions: both lots have the same orientation with similar dimensions.
- Row-house typology: the geometry of the house is constrained and defined as a direct consequence of the urban design scheme.
- High performance goals: criteria related to performance and sustainability were dominant ideas during the process.

- No client constraints: the architect could experiment on solutions, emphasizing the defined goals and priorities.

The main ambition was clearly to reach higher levels of performance and build according to the cradle-to-cradle approach. The high performance goals and the strong geometrical constraints of the row house typology also constrain the scope of possible design dilemmas. Designerly simulation should focus on the definition of optimal envelope properties. The design process can be roughly divided in three main stages:

- Early design: the architect intended to make a completely different design in comparison to his previous house. Besides the higher performance ambitions, the designer intended to adopt a distinct architectural language. The extensive use of wood – also a feature of the first house – was defined early on to minimize the impact of the construction. Several design definitions were still vague at this point, but the geometry of the building and a general idea about the internal layout were available early on.
- Mid-design: the designer decided to adopt in the new house the most noticeable visual feature of the first house: the unusual facade layout of glazed stripes and large windows. The re-use of the concept – which was motivated by artistic reasons – reinforces that both houses are part of the same evolutionary process.
- Detail: the refinement of detailing decisions and efficient systems adopted in the house.

The use of designerly simulation should support decisions directly related to the architectural envelope (properties of walls, roofs and openings). Technical definitions, concerning systems and detailing decisions (e.g. window frames) should be supported by consultancy firms as it involves more specific knowledge and tools.

Even though the analysis of the process was based on an interview with the architect, the identification of three main design stages is not necessarily an accurate reproduction of the process, given the inherent complexity of design practice. Instead, the goal is to identify basic design scenarios that hold some relation with the design evolution.

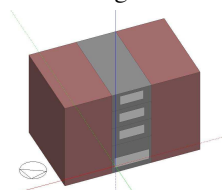


Figure 9 Early design model.

The early design stage model (Figure 9) has a fully defined geometry and a vague definition of building fabric (R-values), internal layout (number of floors), occupation and systems. Occupancy variables (internal gains and schedules) were based on

templates and modified according to information provided in the interview.

Given the fact that the main design priority was to reach higher performance levels, the dilemmas at this stage are affected mostly by pragmatic constraints (ranges of solutions) than by abstract constraints (concepts, ideas, preferences and intentions).

As an example, this paper presents parametric studies to define glazing properties (U-value and SHGC) on both facades and WWR (window-to-wall ratio) on the Southeast facade. The dilemma has the following features:

- Goal: identify the impact of glazing properties on both facades and WWR on the Southeast facade to support related design decisions.
- Dilemma: Considering the intention of adopting a highly insulated envelope ($R=10\text{m}^2\text{K}/\text{W}$), what is the influence of glazing properties (U-value, SHGC and WWR on the Southeast facade)?
- Pragmatic constraints: glazing U-value (1.3 and $0.8\text{ W}/\text{m}^2\text{K}$), SHGC (40% and 70%) and WWR (20%, 40%, 60% and 80%).
- Abstract constraints: high performance goals.

The investigation of optimal glazed area in the Southeast facade was made adopting a WWR of 30% on the Northwest facade (default value). However, the modification of glazing properties (U-value and SHGC) affects the openings on both facades.

A standard heating system was defined to meet the temperature of 18°C . A constant ventilation rate of 3ACH was defined to meet 22°C when the inside temperature is at least 2°C higher than outside. In order to assess the overheating risk with the limitations of the DesignBuilder parametric mode, we defined a hypothetical cooling set point of 28°C .

The heating and cooling loads of the 16 cases allow the visual identification of optimal ranges. Such information can be used as parameters in later design stages. Some aspects can be pointed out (Figure 10):

The best case in terms of heating loads is the highly insulated glazing with high SHGC ($U=0,8\text{ W}/\text{m}^2\text{K}$, SHGC=70%). If cost constraints are an issue, the use of a moderately insulated glazing system ($1.3\text{ W}/\text{m}^2\text{K}$) with a high SHGC (70%) is equivalent to a highly insulated system ($0.8\text{ W}/\text{m}^2\text{K}$) with a lower SHGC (40%) for WWR lower than 40%.

- The cases with high SHGC presented a slight increase of heating loads for WWR higher than 45%. This is related to the ventilation conditions.
- Cases with high SHGC have higher cooling loads. For the best glazing system, the cooling loads start to overcome heating loads when WWR is higher than 55%.
- The combination of both criteria (heating and cooling loads) indicates that an optimal WWR range is between 40-45%. For WWR higher than

45% we observe that cooling loads start to be closer to heating loads.

- If cooling loads can be reduced using summer shading strategies, the glazed area can be increased in later design stages. Requirements of indoor climate can generate further design dilemmas that can be approached with solar tools (shading analysis) or thermal tools (thermal comfort).

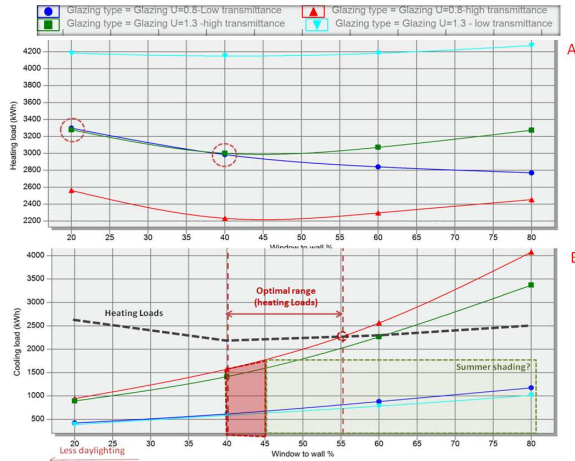


Figure 10 Heating loads (A) and Cooling loads (B)

Interestingly, the final design adopted in the Southeast facade a WWR of 43%, which is the average of the proposed range (Figure 11). The same study was made to define an optimal range for the Northwest facade. The final design adopted a WWR slightly higher than the defined range of 20-30%.

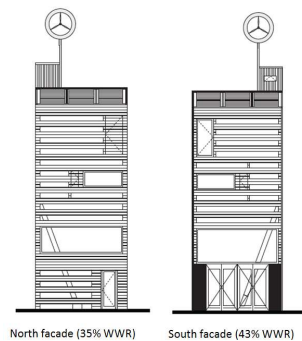


Figure 11 Final facades: concept of the 1st house

In the mid-design stage, the impact of this difference can be quantified in more detail. In this case, the dilemma would have a relevant abstract constraint: the adoption of the same concept used in the first house. Therefore, any modification of the Northwest WWR should preserve this design intention.

CONCLUSIONS

This paper presented the concept of designerly simulation, which aims to combine the power of analysis of tools with the power of synthesis of designers.

The concept focuses on solving architectural design dilemmas using multiple simulation tools. The scope

of each dilemma is affected by constraints that can be directly or indirectly input in the model.

Sources of information such as design principles and design precedents can be used as 'shortcuts' to transform abstract constraints into pragmatic inputs. The attributes related to information extracted from precedents can be tested and improved using simulation tools, which minimizes the risk of using inadequate information.

The paper also presents two examples of designerly simulation processes. The high performance goals combined with the specific constraints of each design led to a more pragmatic study.

The first example was extracted from an ongoing design. The dilemma was intended to investigate the pertinence of a design strategy (trombe wall). The information of the second design process was extracted from an interview with the leading architect. The well defined goals and circumstances led to a more pragmatic investigation.

The use of abstract constraints in simulation models should be approached in more detail in future works.

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REFERENCES

- Bay, J.-H. Cognitive Biases in Design: The case of tropical architecture. (PhD). TU Delft, Delft, Netherlands, 2001.
- Cross, N. Designerly ways of knowing. London: Springer-Verlag. 2006.
- Department of Energy. International Energy Conservation Code. International Code Council Inc. 2009.
- Designbuilder. DesignBuilder Software version 2.3.5.032. 2000-2010.
- Harfield, S. On design 'problematization': theorising differences in designed outcomes. Design Studies, n.28, p.159-173. 2006.
- Lawson, B. What designers know. Oxford: Architectural Press. 2004.
- _____. How designers think: the design process demystified. Oxford: Architectural Press, 4th ed. 2006.
- Morbiter, C. Towards the integration of simulation into the building design process. (PhD). Department of Mechanical Engineering, University of Strathclyde, 2003.
- Pedrini, A. Integration of low energy strategies to the early stages of design process of office buildings in warm climate. (Phd). Department of Architecture, University of Queensland, Brisbane, 2003.