# Design Guidance for Low-Energy Dwellings in Early Design Phases

## Development of a simple design support tool in SketchUp.

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**Abstract.** *Considering the energy efficiency and comfort levels of dwellings, stricter legislation will be applied towards 2020. To reach these requirements, an insight into the energy efficiency becomes essential from the start of a design. However, the uptake of building simulation tools by architects and students to evaluate the energy performance during the architectural design process remains very limited, mainly due to the complexity of these tools. Therefore, this research aims at early design support through an easy-to-use application adapted to the modelling logic of a designer. As architects often use simple CAAD design tools for design exploration, a prototype was established in Google SketchUp. In this context, the paper presents the development of a support tool for low-energy dwellings in early design phases, allowing designers to quickly assess the thermal comfort and energy performance of early design alternatives.*
**Keywords.** *Design support tool; Energy; SketchUp; Architectural design process; Output.*

## PROBLEM STATEMENT

Regarding the trend towards zero-energy buildings in the near future (EU 2010), architects are increasingly forced to consider the energy efficiency of their building designs during the architectural design process. Particularly in early design phases, the architect makes important decisions regarding building geometry and building envelope which strongly influence the final energy performance and summer comfort levels.

Unlike other design aspects, the integration of energy efficiency in design cannot be done intuitively. In practice however, early design decisions regarding energy efficiency are often based only on the experience or intuition of the designer (de Wilde et al. 1999), especially in small projects that lack engineering support (Mahdavi et al. 2003). The assessment of the energy performance is usually not conducted until detailed design phases (Weytjens and Verbeeck, 2010), therefore often resulting in remedial modifications afterwards. In addition to this, students in architecture often experience difficulties with the implementation of technical issues taught in theoretical courses into their design studio work (Lawson 2004). Consequently, there is a clear need for early design support regarding the energy performance of dwellings, for both professional architects and students.

Last decades, many building energy simulation tools have been developed. In contrast to the wide acceptation and uptake of CAD applications in current architectural practice, the uptake of energy simulation tools is very limited (Weytjens and Verbeeck, 2010). This might be explained by the fact that most of these tools are aimed at specialists and require expert knowledge. In this regard, several researchers have attempted to bring energy performance assessments closer to the architect in various ways (Bambardekar and Poerschke,2009; Peters 2011; Attia et al. 2012). One of the methods consists of implementing energy performance assessment in existing CAD applications, to reduce and adjust the data-input to an architect user. Recent developments particularly focus on the implementation with building information models (BIM) such as AUTODESK Revit (Schlueterand Thesseling, 2009; Verstraeten et al. 2008). These models benefit from the possibility to store different types of information, which can thus easily be accessed and retrieved for energy evaluations.

Despite promising developments in this field the integration of BIM in the early design process still seems to be a difficult task (Penttilä 2007). In early design phases, architects seem to prefer simple sketch design tools, such as Google SketchUp (Weytjens and Verbeeck, 2010) [1]. Therefore, to support the design decision-making of architects with regard to energy efficient dwellings, research was undertaken to develop a simple design tool in SketchUp.

Several plug-ins have already been developed to link Sketch-Up with detailed energy simulation programs, such as TRNSYS [2], EnergyPlus [3] and IES Virtual Environment [4]. These plug-ins often require a very specific way of modelling in function of the thermal building model. This way, the tools are able to retrieve the necessary data for an energy evaluation. From the plug-ins listed above, only the data-input and modelling method of the IES plug-in is adapted to the regular working method of architects by automatically retrieving data from a building model and eliminating any restriction for modelling. Besides, also the output of these plug-ins is often not adapted to architects. Feedback is usually provided in an external application, which impedes the fluidity of the design process. Furthermore, due to technicality, the representations of results are offered by interfaces that lack a relationship between the output and the design, making it difficult for architects to detect patterns for understanding their design impact on performance (Bleil de Souza 2009). In this regard, both literature review and focus groups with architects revealed that the visualization of the results in real-time might be a good solution to guide the design decision-making process of architects (Bleil de Souza 2009; Schlueter and Thesseling, 2009).

This paper reports on the development of a prototype in SketchUp, which is adapted to the early design process and enables architects to perform a simple and quick energy and summer comfort analysis.
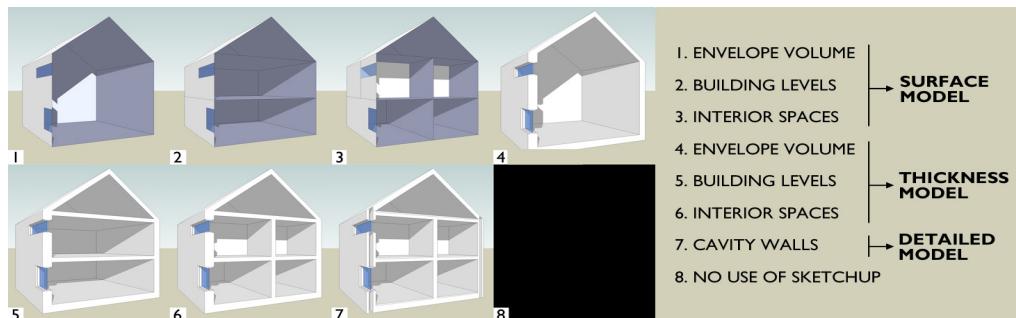


Figure 1
Different modelling techniques that can be used in Google Sketch-Up.

## METHODOLOGY

The research presented here is part of a larger doctoral research project. Previously to the development of the prototype, the architects' needs and preferences for a simple energy design tool were examined. These results are not included in this paper, but are described in the research of Weytjens et al. (Weytjens et al. 2010).

Research shows that for the acceptance of an energy design tool by architects, a link with building regulations is very important (Mahdavi et al.2003; Weytjens and Verbeeck, 2010). Therefore, the integrated energy calculation model is based on the Flemish version of the European Energy Performance of Buildings Directive (EPBD), i.e. the EPB [5] and this monthly based steady state model is adapted to allow the energy performance evaluation in an early design phase by using default values for unknown input data (Weytjens and Verbeeck, 2011.). In addition to this, an extra module for summer comfort evaluation was embedded within the prototype. Both calculation models are programmed in MS Excel.

The elaboration of the prototype consisted of five major steps. First, a small-scale survey was conducted among Flemish architects to identify specific modelling issues and methods used in SketchUp. Based on these results a specific modelling logic was chosen as starting point and codes were established to access and retrieve the necessary geometrical data for an energy analysis from a 3D model. In a third step, a user interface was created to assign properties to the geometry and provide additional data needed for energy evaluations. Then, a link was established with MS Excel to perform the calculations. Finally, a method was developed to visualize the output extracted from Excel into the SketchUp environment. A detailed description of the prototype is provided in Geyskens (2012).

A first version of the prototype was demonstrated to potential users and first feedback was retrieved from three focus groups.

## SURVEY

First of all it is important to gain insight into the way architects work and model a dwelling in SketchUp throughout the design process, to adapt the plug-in to an architect user. Hence, a small-scale online survey was conducted among Flemish architects. A link to an online survey was distributed via e-mail to the entire user club of a distributor of CAAD software in Flanders, to be able to reach particularly architects who use SketchUp. Architects could participate during a time span of two weeks, which resulted in 71 completed enquiries. Information was gathered about modelling methods used by the architects and their possible dependencies with different design phases such as conceptual design, preliminary design and final design.

To uncover a modelling difference throughout the design process, eight images were included, each representing a different modelling technique (figure 1). The participants were asked to match one image with each proposed design phase. A black image at the end was added for architects that do not use SketchUp in a particular phase. The results are shown in figure 2.

Figure 2 demonstrates that the architects' modelling logic in SketchUp strongly depends on the design phase. In the conceptual design phase 44% of the participating architects model according to technique 1 of figure 1, representing a surface model which describes the building envelope and a single volume defining the entire building (i.e. rooms and intermediate floors are not modelled). In the preliminary design phase 41% uses models with thickness and separate zones (rooms) as proposed in technique 6 of figure 1. Although not expected and although 47% mentioned not to use SketchUp in the building permission phase, 53% is still using one of the presented modelling techniques even in this final phase. Nevertheless, it is clear from figure 2 that most architects draw more and more in detail as the design process advances. Furthermore a majority (79%) was interested in early design evaluation of energy performance and summer comfort as plug-in for SketchUp.
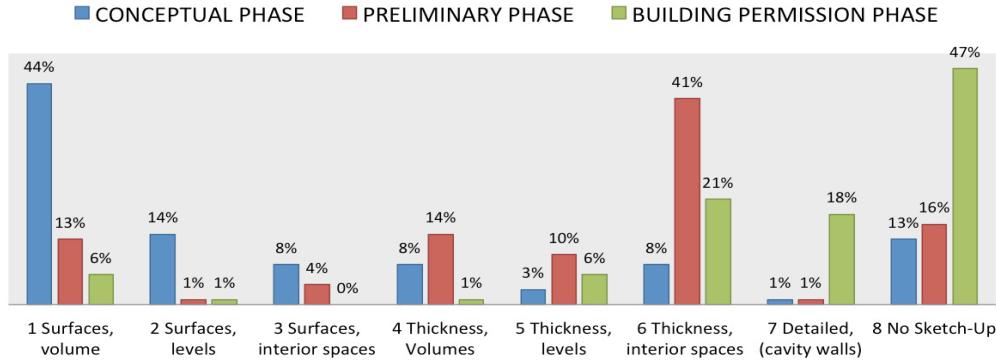
Chart legend: ■ CONCEPTUAL PHASE  ■ PRELIMINARY PHASE  ■ BUILDING PERMISSION PHASE

Data by category:
- 1 Surfaces, volume: 44%, 13%, 6%
- 2 Surfaces, levels: 14%, 1%, 1%
- 3 Surfaces, interior spaces: 8%, 4%, 0%
- 4 Thickness, Volumes: 8%, 14%, 1%
- 5 Thickness, levels: 3%, 10%, 6%
- 6 Thickness, interior spaces: 8%, 41%, 21%
- 7 Detailed, (cavity walls): 1%, 1%, 18%
- 8 No Sketch-Up: 13%, 16%, 47%

*Figure 2*
*Modelling methods used in Google Sketch-Up through the design process.*

Other questions were related to the general use of particular features in SketchUp, including the use of groups and components for different purposes. The results conclude that layers are used by 79% of the participants to show or hide geometry, 63% works with assigned materials, 46% uses groups to combine the complete design, 48% uses components and 56% uses groups to isolate different construction elements. Based on the results of the survey, the first steps towards a prototype were established.

## PROTOTYPE

### *Objectives*
With regard to the holistic and integrative nature of design solutions (Lawson 2004), energy assessments may only require very little time from the designer, as this is not their only concern. A first prototype in SketchUp aims at early design support through an easy-to-use application. Considering the usability of a simple energy tool in early design phases, the data-input must primarily be reduced to a minimum. This allows designers to analyse different design alternatives and configurations very quickly. Also, data input and output should be presented in the same environment for easy adaptation and interpretation of data. Therefore, a well-structured user interface will be included which provides a clear legibility between the 3D model and its performance. Additionally, the architects' specific working method must

be taken into account by minimally interrupting the design process. To achieve this, the prototype will be adapted to the specific modelling techniques of architects. Furthermore, calculations and feedback about energy efficiency and summer comfort should be retrieved without any large effort. Special attention was paid to these aspects when developing the prototype.

Based on the results of the survey, two distinctive modelling methods were addressed to reach as many users as possible and to cover different design phases. One method uses a model with a particular thickness with different rooms as shown in technique 6 of figure 1. This will be called the 'preliminary model'. The other method supports very early assessments and is based on a surface-model of the building, further in this paper called the 'conceptual model'. This method addresses diverse modelling techniques as shown in example 1, 2 and 3 of figure 1, offering modelling flexibility towards architects.

Because of programming complexity, the preliminary model was developed first, which could be easily adapted to the conceptual model afterwards.



*Figure 3*
*Custom Toolbar.*

### Input and user interface design

The user is provided with a clear toolbar in a logic order for every function of the tool (figure 3). This simple toolbar was created in SketchUp and consists of only 5 icons, each representing a particular step in the description of the energy model. Both data-input and output take place in SketchUp.

From left to right the following icons or functions are distinguished:

- *'Project Information'* shows template data such as the ambition level of the project (relevant for the default input data and associated construction types and installations).
- *'Analyse Spaces'* automatically detects interior spaces (zones) and allows architects to choose whether a space is heated or not.
- *'Construction Properties'* automatically distinguishes roofs, walls, floors, etc. and allows assigning component materials in (multiple) layers (in case no default input data are used).
- *'Project Results'* shows the results of the energy performance and comfort levels.
- *'Library'* enables to build construction components and define new materials.

Next to these buttons, fundamental aspects of usability are integrated by combining a pop-up user interface to assign material properties and construct the library, and a 3D interface drawn in SketchUp. The 3D interface is a special feature in the tool and utilizes functionality of SketchUp to design a user interface. It consists of a new interaction method that is created into the modelling environment using simple cubes (figure 4). These cubes appear automatically next to the building model when the options "analyse spaces" or "construction properties" are used and serve as 3-dimensional buttons to assign different properties. The designer can click very intuitively on the model (a zone for example), and assign properties to the selected parts (e.g. heated or not-heated) by clicking on the specific cube with the right property. This allows architects to easily and quickly perceive the composed thermal building model. As a result, it optimizes the visual reference between the model and the functionalities of the tool.

In addition to this, speed is taken into account and therefore the required data-input is adapted to early design phases. By giving the user the possibility to use predefined standard data from templates, a first analysis can be made very fast with only very few data-input. In this context, default values are chosen based on the ambition level of a project, including "standard", "standard plus", "low-energy" and "passive house" (Weytjens and Verbeeck, n.d.). Based on the ambition level, predefined values are set in several templates for specific U-values, installation properties, etc. The different default values can be adapted as well and the results are shown automatically within Sketch-Up, without involving other software.

### Data extraction

As Google SketchUp is not BIM related, the search for data extraction from a Sketch-Up model becomes of great importance. The necessary input data to perform an energy and summer comfort assessment rely on the available geometrical data, element properties and additional data such as installations. All input data are defined and retrieved from SketchUp: geometrical data and data related to construction components can be automatically extracted from the 3D model, whereas additional data such as the properties of installations are defined using simple dropdown menu's. Next, these data have to be extracted from the model and sent to an Excel calculation module. To achieve this, the application is constructed in the embedded Ruby Application Programming Interface (API) [6].

**Geometrical data:** An energy performance calculation according to the EPB requires information about the building geometry and the envelope. All geometrical data, such as building volume, surface areas and glazing areas are automatically derived from the 3D SketchUp-model with basic code. Based on these first values, the total loss area is derived, followed by the compactness and the gross floor area of the design. Further, orientation angles are extracted by an algorithm that compares the solar north vector with the normal vectors of each individual com-
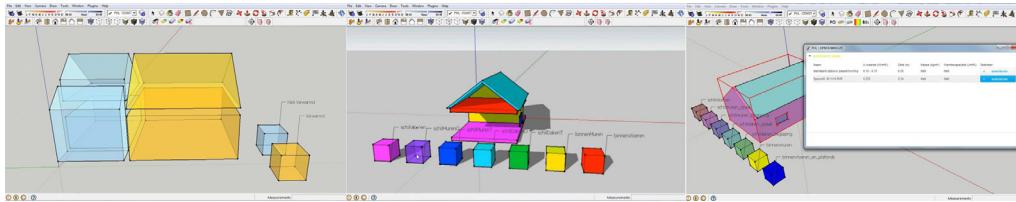
ponents. Consequently, inclinations of the surfaces are derived, as they will serve for automatically distinguishing different construction elements, such as roofs, exterior floors, interior floors, outdoor walls and indoor walls. By assigning transparent or translucent SketchUp materials to particular elements in the model, the automatic recognition and extraction of windows is realized. In addition to this, the different rooms in the model are also automatically recognized. This is of minor importance for energy (EPB) evaluations, but is particularly important for summer comfort evaluation, which is incorporated as an extra module. Further, the user can specify whether different rooms are inside or outside the insulated envelope, indicating whether they are heated or not (left image of figure 4).

**Assigned construction properties**: Construction parameters that are required for energy assessment can easily be assigned to the geometry by first clicking on the "construction properties-button", followed by simply clicking on the particular elements in the 3D model.  Then, a pop-up user interface appears as described earlier (right image of figure 4). Users can choose specific predefined construction components from a personalized material library and assign them to particular construction elements such as walls, floors and roofs. Furthermore, predefined templates are incorporated facilitating and reducing data-input to a strict minimum. This way, architects are able to focus on conceptual and architectural solutions to optimize the energy efficiency of the design and more detailed input can be provided as the design develops.

**Additional information:** Next to geometrical data and their assigned construction properties, basic information related to heating, cooling, ventilation and renewable energy systems is included. These data are not connected with the 3D geometry and can be entered manually by the user or implemented with default values from a specific template. This information can be specified using the button "project information".

### Preliminary model and conceptual model

As the prototype incorporates two ways of modelling, the recognition of the rooms slightly differs in both models.

Considering the "preliminary model", a total enveloping volume is automatically generated around the building model. The solid components are then subtracted from this inclusive envelope, resulting in all different rooms (left image of figure 4). This method specifically requires the use of SketchUp groups for construction elements, and hence imposes few modelling rules to the user. Nevertheless, the survey revealed that architects are familiar with this way of modelling.

The conceptual model on the other hand, does not contain solids and thus uses a different algorithm for recognizing volumes. This model does not impose specific drawing or modelling rules to the user which makes it more user-friendly.

However, for both models, the underlying process to recognize distinctive rooms is not important for the user and thus remains invisible. The optimization of these processes is still in development, but can already be applied for simple designs. At this moment, both modelling methods are integrated in separate plug-ins, but the intention is to create a single plug-in in which the user can freely use one of the two modelling methods.

### Calculation

The project results can be calculated after all necessary data are extracted and defined. The calculation method is based on the steady-state one zone calculation model of the Flemish EPB, which is programmed in MS Excel. It calculates transmission and ventilation losses, the useful internal and solar gains, and the energy consumption for heating and cooling on a monthly base.

In addition to this, an extra module for multi zone evaluation of summer comfort is also integrated. In the most significant month July, the hourly interior temperatures are calculated for each zone separately. The results return the evolution of the temperature in this period, which allow estimating the risk on high temperature levels during summer. These depend on the exterior temperatures, the heat gains (solar and internal gains), the heat losses (transmission and ventilation losses) and the heat capacity of the building. The heat flux between different interior neighbouring zones is not taken into account. Climate data are retrieved from the Test Reference Year for Ukkel (BE).

With VBA (Visual Basic for Applications), a link to the excel calculation modules was established but remains invisible for architects. This way, the architect remains in a single and familiar (modelling) environment and the design process is minimally interrupted. However, the possibility exists to visualize Excel during the energy assessment. Further research will define whether this is preferred among architects or not.

The plug-in was validated based on a simple 3D model in a comparison with the official software imposed by the Flemish Government. At this moment, the prototype is useable for very simple building 'blocks', but it will be elaborated further in the future.

### Output

The output is visualized in the SketchUp environment. Values that correspond with legislation, such as the insulation level (K-level) and the energy performance level (E-level), are shown to the user in small text boxes. They are shown as a range if default values are used, defining the possible deviation for the final performance in the end. For summer comfort, values of maximum and mean temperatures are also provided in small text boxes, and in addition to this, results are shown on the model using colours (figure 5). By visualizing the output in the actual building model, a first step is accomplished towards a clear link between output and performance.

Nonetheless, with regard to energy assessments, it is essential to further adjust the output in design support tools for designers. Upcoming research will define how the output can be optimized. The prototype strived towards real-time feedback, but this is not fully accomplished yet and further effort is necessary to achieve real-time updates of the output when modifying the design. This is of major importance to make architects aware of the consequences of their design decisions with regard to energy performance and summer comfort. The assessment of different design alternatives will also be elaborated in future research and the visualization of the output requires further refinement.

## FEEDBACK FROM DESIGNERS

A first rough prototype of the preliminary model was presented to architects in three focus groups. Two groups consisted of architects in practice and one of master students in architecture. In general, participants had a positive impression of the tool. The use of SketchUp and the 3D interface using simple cubes to assign properties to the model was appreciated for its intuitiveness. However, architects emphasized the importance of a conceptual model and also perceived a difference between a model in SketchUp for presentation and design versus energy assessment purposes. Hence, the surface model is very important as it also minimizes modelling restrictions. The students were used to model with thicknesses, such as the preliminary model. This shows the importance of integrating both modelling methods.

To serve as a useful design tool and thus informing on the design rather than post-evaluating it, real-time feedback while designing appeared to
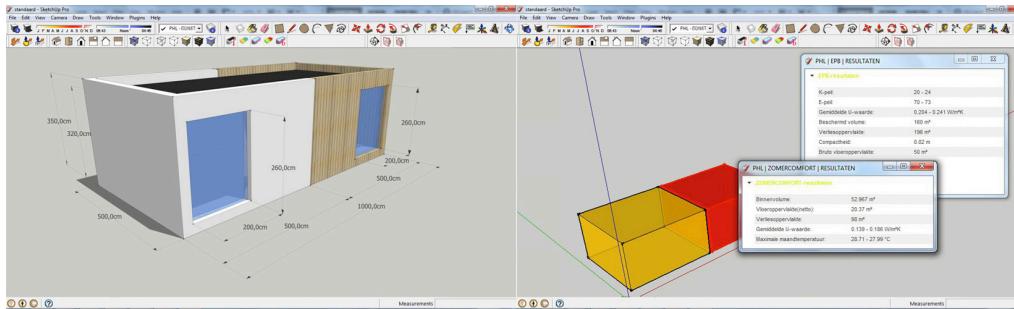
be very important in all groups. Furthermore, architects also indicated the importance of transparency, including an overview of all input data used for calculations such as areas, glazing area per orientation etc. Further cooperation with architects is necessary and will be set up in the future. In particular, user tests with architects will be conducted, allowing further iterative prototyping.

## CONCLUSION

As energy efficiency is an element in the multi-criteria context of architecture, building simulation tools can provide essential feedback during the design process. Considering the evolution of BIM towards energy performance calculations, architects rather use it for managing data in projects. It serves for more detailed design stages in particular, as it still seems difficult to integrate BIM applications at the beginning of the process. In contrast, simple tools are necessary to quickly estimate performance criteria in early design phases, with rather limited input data. This paper emphasized the importance of adapting tools to the design environment and modelling techniques of architects. Consequently, designers also need results on energy efficiency that visually connect with the building elements they are adjusting. This way, they can learn how the model behaves at certain criteria and particularly experience impact levels of design decisions. Hence, the way in which the output is presented is very important and needs further research.

Developed with a design perspective, the pro-

totype already seems to address the first needs of architects. As literature review and focus groups already confirm, real-time feedback should be a next step towards a useful integration in the architectural design process. Therefore, this tool will be further developed in close cooperation with the final users.

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