THE MEANING AND VALUE OF INFORMATION FOR ENERGY-CONSCIOUS ARCHITECTURAL DESIGN

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ABSTRACT
Architectural design is a complex process that depends on the information available to the designer to achieve the design task. Information provided by design tools during all stages of the design process may have a critical value on the success of the design alternative. However, many of the existing design tools are still rudimentary with many limitations for use by designers in early design stages of any architectural project. The paper presents several approaches for design tools for architects to support the entire design process. Moreover, this work will demonstrate how existing modeling tools, widely used by architects for modeling purposes only, can be easily enhanced, presenting information with a new meaning most valuable for design generation, giving architects new ways to make informed design decisions towards high-performance architectural and urban design.

INTRODUCTION
During the conceptual design phase of buildings and urban areas, the designer deals with different geometrical characteristics related to the buildings’ orientation, height and width, in relation to open spaces and pedestrian sidewalks. New buildings may create a different microclimate, like changing the wind regime, daylight access, and shading of existing buildings and neighborhoods. Protecting solar and daylight rights is a complex task, strongly influenced by early decisions made by the designer.

The determination of a preferable design solution becomes especially complicated due to mutual influences. For example, the orientation and proportions of streets will influence the exposure of sidewalks to the winter sun, as well as creating the required shading during summer. On the other hand, ignoring the solar rights at the stage of the preparation of a master plan may cause unrecoverable discomfort conditions around and inside the buildings, and seriously compromise their energy performance. The early stages of this process characterize themselves by a constant search of a design direction. Nevertheless, decisions taken in those moments can determine the success or failure of the proposed project (Hari A., 2001). This was also verified by a study on the design principles of high-performance intelligent facades for hot climates, in terms of both building energy consumption and user comfort (Ochoa and Capeluto, 2008). Figure 1 shows the relation between information and design freedom during the different stages of the design process (Ullman, 2003). As we can see, despite the fact that there is not much information during the early schematic stages of the design process, there is a high degree of design freedom and then major significant decisions are made at this time.

For these reasons, it is imperative that design tools could support architects from the very beginning of the design process, providing meaningful information according to the design stage. However, existing design tools are still rudimentary with many limitations for use by designers in early design stages of any architectural project. They generally are aimed to external consultants and require exact data in a stage when designers consider conceptual ideas from a range of options rather than precise details and numbers. Design tools that suggest solutions based on ideas are still rare (Ochoa and Capeluto, 2009).

Passive Solar Design
The idea of ensuring solar access is not new; the Roman Empire had solar access laws; the "Leyes de Indias" (The Law of the Indies) that were applied on the foundation of new towns in America consider block layout and street orientation to allow solar access, and the Doctrine of Ancient Lights protected landowners’ rights to light in nineteenth-century...
Daylight Access

Lighting is responsible for 30% to 50% of all the energy utilized in commercial and office buildings. Daylight can be used to reduce lighting energy use and the heat gains associated with electric lighting. The efficient utilization of daylighting can dramatically reduce the total electricity load and the peak demand.

However, the availability of daylight in certain areas of the city can be difficult due to the influence of the external built environment. In medium and high-density zones, where generally office buildings are located, the lack of light from the sky at street level can cause design problems for the architect that wishes to use daylight to provide a high quality-working environment and as an energy efficient design strategy. Tall buildings and elongated obstructions can affect dramatically the amount of light received and its distribution inside the building (Capeluto, 2003, Li et al., 2006). Given that only the upper floor in multi-story buildings can eventually make use of skylights, generally the only source of daylighting inside the office space is through side windows. In addition, the provision of side-daylit offices places limitations on building depth and interior organization. In dense urban areas buildings' arrangement is the most important factor affecting daylighting as well as the thermal comfort of public and private open spaces. The surrounding built environment can seriously affect the possibility of using daylight inside offices.

DESIGN TOOLS

Different design tools for solar rights and daylight access were developed. Broadly, we can classify these tools into generation tools and evaluation tools. Generation tools aid to define the proper geometry to achieve a certain performance. Performance-driven form generation refers to the idea that performance data can be used to generate architectural form. Shaviv (1975) proposed a method and a computerized model for the design of fixed external sunshades. The method was extended later for the generation of solar rights envelope for the design of solar communities (Shaviv, 1984). Arumi (1979) developed a computerized model that determines the maximum allowed height of a building that does not violate the solar rights of the existing neighboring buildings. Knowles (1981) suggested a method for assuring solar access to each residential unit in a community. De Kay (1992) made a comparative analysis of various envelopes allowing daylight access. Schiler and Uen-Fang (1993) developed a computer program for the generation of solar envelopes for flat-rectangular sites based on Knowles work, and Koester (1994) presented energy armatures using passive resources like winds and rain water, for urban sustainable development. The model SustArc developed by Capeluto and Shaviv (2001) uses the Solar Rights Envelope (SRE), Solar Collect Envelope (SCE) and Solar Volume (SV) data as target.
functions (Fig. 2). These solar envelopes define the space of all possible design solutions that either considers solar insolation or solar shading. SustArc allows the generation of different building configurations, ensuring solar rights of each neighboring building, and open spaces like sidewalks, gardens and squares. The model presents the maximum available volume in which it is possible to build without violating the solar rights of any existing building, as well as the designed one. The Solar Rights Envelope presents the maximum buildings’ heights that do not violate the solar rights of any existing buildings, during a given period of the year.

The Solar Collection Envelope presents the lowest possible locus of windows and passive solar collectors on the considered building’s envelope, so that they are not shaded by the existing neighboring buildings, during a given period of winter.

Clearly, it is possible to determine the volume between both envelopes. This volume is called the ‘solar volume’ (SV), and can be defined as follows: The Solar Volume contains the maximum buildings’ volume to be designed so that these buildings allow solar access to all the surrounding buildings, and at the same time are not shaded by them, during a given period of the year (Fig. 2).

Figure 2 Solar Envelopes: Solar Rights Envelope (1), Solar Collection Envelope (2), and Solar Volume

This type of generative design tools has the potential of providing meaningful information to support design decision during conceptual design stages.

Evaluation tools, on the other hand, analyse the performance of a given design alternative. Although architectural design processes ends up with a single built design, during the design process numerous design alternatives are generally created and evaluated. Examining several design alternatives meant that labour had to be dedicated to the creation of every singular design alternative. As architectural design is often performed under tight schedule and budget, the amount of resources designers have to investigate design alternatives is highly limited.

In practice, the large majority of existing evaluation models is geared to simulate and evaluate finished alternatives. According to Ochoa and Capeluto (2009) they are unsuitable as practical design aids for architects, since they share the following characteristics:

- Not all of them follow the logic of the architectural design process, which involves an iterative and sometimes loose method based on incoming information, stated principles and mental schemes.
- Early design decisions are based on vague “ideas” that cannot be evaluated with tools that rely on exact data. They require complex input procedures, together with translations from one format type to another.
- The majority of evaluation programs are designed for use by consultants, generally engineering companies that enter the design field very late, when main geometric characteristics of the building are already fixed.
- Input of current evaluation models needs detailed information and precision not known and not relevant at the beginning. Tools can also have complex interfaces that require much time to learn and use.
- Both factors can distract from the design activity itself.
- Most tools are dedicated to evaluate and model a certain finished alternative, not to suggest and evaluate different design options and directions. This implies fitting an idea to the modelling tool, thus filtering out information that could be useful or distorting the process.
- Architects trying to use these tools are thus subject to evaluate finished alternatives using a trial and error approach. This slows down production schedules or forces to depend exclusively on factual experience.
- For complex projects on the boundary of his or her expertise, the designer has few criteria about which design direction to develop in order to pass from idea to concept.

In the next section, we will demonstrate how existing tools can be enhanced to provide information with a new meaning for design. It will be done through the use of SunTools (SunTools website), implemented using Ruby scripting language as a plug-in for the Sketch-Up modelling program (Google Sketch-Up website), which allows visualization of sun position and the sun path; produces axonometric views from the sun to easily analyze mutual shading and solar access and penetration at any design stage, providing evaluation results that can be used as generative information. The analyses are easily done without the need of exporting the geometric data to external programs, using the same working 3D schematic model. We will discuss as well, new developments that allow using evaluation of solar irradiance in complex urban environments as a design tool, as part of the toolbox available to designers. These tools aim to serve students, teachers, architects and consultants from the early design stages, to include solar consideration in the design.
MEANING OF INFORMATION IN DESIGN

As stated above, decisions made during early design stages may have great impact on energy performance of buildings and obtained comfort conditions. SunTools was developed as an attempt to investigate the possibility of using existing design tools, widely used by architects, providing the designer all along the design process with new performative information that can help designers in the generation of energy efficient design solutions.

Sun Path and Sun Position

The key to designing a successful passive solar building is to best take advantage of local environmental conditions and climate. The ability to improve building performance and comfort as well as the quality of open spaces in winter and summer is fundamentally dependent on the understanding of the seasonal variations in the sun's path throughout the day in relation to the designed building.

Fortunately, common modelling tools widely used nowadays by architects very early in the design process provide capabilities of visualization of accurate shadow casting by the design during various times of the year. This feature allows quick visualization and understanding of mutual influences among buildings at certain times.

However, these tools generally do not allow visualizing the sun itself or its path despite that they calculate internally its relative position in the sky, according to the geographical definitions of the model. Visualizing the sun path during a required period of the year or at a certain date and time can help to understand in a better way the impact of the sun in relation to the project and its surrounding areas (Autodesk-Ecotect website). Since this information exists in the model is very simple exposing it to the designer creating a new layer of information to work with (Fig. 3).

Sun Penetration

Once the solar geometry information was incorporated as part of the working model it can be used and manipulated in order to perform evaluations of design alternatives. Using this information SunTools allows assessing Sun Penetration and Solar Access at any specific point (internal or external) of the project (Fig. 4). This powerful evaluation is produced taking advantage of common capabilities of modeling tools of producing custom views from preset viewing points and directions.

The evaluation allows designers using their own 3D working models understanding in one comprehensive view the periods of exposure and shading for the analyzed position in the project.

Furthermore, the designer can see and understand the times and causes of overshadowing, and modify accordingly the design in order to obtain the desired performance. This feature can be also applied to study Sun Penetration inside buildings, as shown in Fig. 5. In this example, the geometry of the shading devices can be easily modified interactively as necessary to protect the building and achieve the required performance.
Sky View

In a well-designed space, daylight reduces energy costs, enhances the visual quality, and provides others psychological benefits that are hard and expensive to imitate with electrical lighting. The availability of daylighting in certain areas of the city can be difficult due to the influence of the external built environment. The surrounding built environment can seriously affect the possibility of using daylighting inside buildings and compromise daylight availability at street level.

The penetration of daylight into the building depends on many design parameters, among them the depth of the room from the window wall, ceiling height, internal reflectances, window orientation, shape and size, and optical properties of the glazing. It must be stated that most of these factors are unknown by the designer at the early design stages. However, the most significant factor is the availability of daylight outside the building, which can be seriously affected by external obstructions like neighboring buildings or trees.

According to Capeluto (2003), the sky solid angle (SSA) presents the solid angle subtended by the path of the sky visible from the studied point. The SSA is proposed as a means to assess the influence of the external obstructions on the availability of daylighting inside buildings. There exist a correlation between the SSA and the DFave, serving as an indicator of the daylighting potential of the site.

The solid angle subtended by a surface is defined as the surface area of a unit sphere covered by the surface’s projection onto the sphere. This method can help architects consider, evaluate and as a consequence make design decisions by keeping in mind the daylighting potential (or limitations) of the site, and its implications on building design. It can provide also valuable information for authorities trying to regulate development in a way that considers daylight as a key for urban development and ensures an acceptable access to light for different city zones.

With SunTools, the SSA can be easily determined using the 3D model that contains the volumetric information of the studied built environment. The method consists in tracing rays from the studied point in all directions to the sky vault and determining if it is visible or obstructed from this position. In this way the SSA and the percentage of the visible and obstructed sky can be calculated. Moreover, the visible and/or obstructed part of the sky vault can be visualizes as part of the working model. Supplementary information can be super imposed to provide extra information to the designer as seen in Fig. 6 (down) and Fig. 7 showing together sun paths and visible sky vault.

In the same way, additional information can be added gradually according to subjects and questions that may rise in any design stage, as solar irradiance on the design of building envelope or open spaces, providing new layers of valuable information as shown in Fig. 8 (IR4SU currently under development as part of SunTools). This layer of information containing solar irradiance maps can be used by designers as an aid designing building facades and roof, besides of its quantitative value in assessing exposure of windows and solar systems.
CONCLUSION

This paper discusses the meaning and value of performative information presented to designers during their work throughout the different stages of the design process. It presents different approaches for design tools for architects allowing generation and evaluation of design solutions. It demonstrates through the development of SunTools, a plug-in for SketchUp, how existing design tools can be enhanced in order to overcome limitations of existing tools and provide architects with evaluations that have generative value using the same 3D working model. Using the same model for performing the evaluations allows making changes interactively to improve and adapt the design to a required performance. SunTools is being extended to include evaluations of additional subjects as new layers of information that may contribute to generate design based on solar and daylight access Information.

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