High Quality Solar Architecture: Do Architects Have Tools Supporting Early Design Phase Decisions?

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Abstract

This paper presents the results of a "State-of-the-art" review of 56 computer tools (CAAD, visualisation and simulation software) that architects currently use at early design phase (EDP) or other phases of building projects. This work was carried out as part of Subtask B of the International Energy Agency (IEA) Task 41: Solar Energy and Architecture. The results reveal a lack of advanced solar tools for EDP work, systemic specialization of available software, a lack of clear numerical feedback yielding informed decisions at EDP, a lack of clear information about physically-based rendering, and a lack of tools for architectural integration of active solar systems.

1. Introduction

The amount of solar energy reaching the surface of the Earth is so vast that in one year, it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined [1]. In spite of this fact, a large portion of the potential to utilize solar energy still remains unused [2]. According to the International Energy Agency [3], this is caused by the following: 1) economical factors, 2) lack of technical knowledge, 3) reluctance to use "new" technologies, and 4) architectural (aesthetic) factors.

The integration of solar energy systems and technologies in existing and new buildings will be greatly facilitated in the future if architects are informed, aware and engaged in the development of solar energy in buildings. Architects should also by aware of the potential, limitations and characteristics of solar energy through the use of passive and active approaches. The goal of high quality solar architecture is to achieve a good balance of passive and active solar utilisation on the building envelope, including daylight optimisation in order to reduce electricity use for electric lights.

1.1. Early Design Phase (EDP)

Architects have a significant role to play in the development of solar energy systems and technologies in buildings because EDP decisions (building orientation, shape, openings, etc.) are primarily the responsibility of the architect. These decisions made during the first few weeks of design have an enormous impact on the durability, performance, energy consumption and the lifecycle cost of building projects [4, 5]. Approximately 80% of the design decisions that influence a building's energy performance are made by the architect in the EDP. It is also crucial for the architect to feel s/he has a "free" hand during the design process, i.e. to have the capacity to easily modify a building's overall volume, geometry, orientation, etc. The changes made on these parameters should be connected to a direct, explicit feedback about passive solar gains, daylight utilization and active solar systems' performance. Methods and tools used at EDP should support key energy related decisions and allow further development of the project at the detailed design phase.

2. IEA Task 41: Solar Energy and Architecture – Subtask B: Methods and Tools for Solar Design

This review was carried out within the context of Subtask B of the International Energy Agency (IEA) Task 41: Solar Energy and Architecture. The ultimate goal of Task 41 is to support the development of high quality solar architecture, with focus on the architectural profession, as a key factor in the future evolution and implementation of solar energy systems in existing as well as new buildings [6].

To achieve these goals, the work plan of Task 41 is organised according to three main subtasks:

Subtask A: Architectural quality criteria; guidelines for architects and product developers by technology and application for new product development.

Subtask B: Guidelines for the development of methods and tools for solar architecture focusing on EDP and tools for the evaluation of integration quality of various solar technologies.

Subtask C: Integration concepts and examples, and derived guidelines for architects.

Subtask B pursues the goal of examining methods and tools used by architects at EDP in order to: 1) identify obstacles preventing architects from using existing methods and tools for solar building design; 2) identify important needs for new or adapted methods and tools to support architectural design and integration of solar components at EDP; 3) provide clear guidelines for developers of digital tools, with focus on EDP.

3. Methods

To reach the goals set, Subtask B of the IEA Task 41 uses two main paths: 1) an exhaustive review (State-of-the-art) of existing methods and tools used by architects is carried out; 2) an international web-based survey is sent to building practitioners in 13 countries.

3.1 Objectives and scope of the State-of-the-art review

This paper presents the results of the "State-of-the-art" review of existing computer tools that architects currently use at EDP or other phases of building projects. The aim of this State-of-the-art is to analyse the current software landscape for EDP of building projects, to identify missing software tools and/or missing functionalities required for supporting solar design and the integration of solar systems and technologies.

3.2. Method of State-of-the-art

This review focuses on computer tools rather than analytical or graphical tools. The review covers a total of 56 software classified according to three categories: 23 computer-aided architectural design (CAAD) tools, 13 visualization tools and 20 simulation tools. CAAD software include BIM applications, which are, according to the American Institute of Architects, a model-based

technology linked to a database of project information [7]. The tools included in the review are listed below:
CAAD tools: Allplan, ArchiCAD, AutoCAD, Blender, Bricscad, Caddie, CATIA, CINEMA 4D, DDS-CAD, Digital Project, form•Z, Google SketchUp, Houdini, IntelliPlus Architecturals, Lightworks, Maya, MicroStation, Revit Architecture, Rhinoceros 3D, SolidWorks, Spirit, Vectorworks, 3ds Max.

Visualization tools: Artlantis, Flamingo, Kerkythea, LightWave, LuxRender, Maxwell Render, Mental Ray, POV-Ray, RenderMan, RenderWorks, RenderZone, V-Ray and YafaRay.

Simulation tools: bSol, DAYSIM, DesignBuilder, Design Performance Viewer (DPV), Ecotect, Energy Design Guide II (EDG II), EliteCAD, BKI ENERGIEplaner, eQUEST, Green Building Studio, IDA ICE, IES VE, LESOSAI, Polysun, PVsyst, PV*SOL, Radiance, RETScreen, T*Sol and VisualDOE.

The programs reviewed were selected by the group of architects – practitioners active in European offices, engineers, consultants, researchers and university professors involved in IEA Task 41. The review has also benefited from the assistance of a few software developers.

Information collected from literature, scientific and professional publications and official software websites was translated into short structured texts describing each program with key features and information regarding the following items:

- Name, supplier, site, contact, last version, cost;
- Functions;
- Design Stage, users;
- 3D modeling capability;
- Rendering capability (relevant to daylighting estimation - physically based or not);
- Import/Export (in order to evaluate the interoperability of the software);
- Coordinates (what type (if any) coordinate system the software uses).
- Predecessor software, successor software (in complement to the Import/Export section (and often based on its results);
- BIM (if the software supports the .ifc file format and is, therefore compatible with BIM applications);
- Actual solar calculation (methods of calculations of passive solar gains, daylight utilization and sizing of active solar systems like PV (photovoltaic) and ST (solar thermal)).

4. Results of the State-of-the-art

This section presents an overview of findings of Report DB.1 State-of-the-art of digital tools used by architects for solar design [8]. Detailed descriptions of all reviewed software can be found in the report.

4.1 CAAD tools

4.1.1 Overview of available CAAD software for the prediction of passive solar gains

There are many CAAD software today which include some form of connection to an energy simulation program (e.g. Green Building Studio, Ecotect, EnergyPlus, and IES VE), thereby allowing passive solar gains predictions. Amongst the CAAD tools reviewed, the following BIM applications offer the most interesting possibilities for energy simulations including passive solar gains predictions: Allplan, ArchiCAD, DDS-CAD Building, MicroStation, Revit and Vectorworks. Google SketchUp, which is not a BIM application, also integrates many plugins: IES VE-Ware, OpenStudio, and Google SketchUp Demeter, which allow performing thermal simulations based on IES VE, EnergyPlus and Green Building Studio respectively. Google SketchUp is widely recognized for being used at EDP and is often used in the architect's workflow as a predecessor software to another more complex BIM or non-BIM application (e.g. AutoCAD).

None of the other CAAD software examined in this review, including AutoCAD, which is certainly one of the most widely used software in the world, do not directly support the calculation of passive solar gains, either at EDP or at detailed design phase. However, AutoCAD models (.dwg) can be exported to Ecotect or to other simulation software since the .dwg format is a widely accepted file format. A plugin called EnergyPlugged is also available in beta version for running EnergyPlus from AutoCAD.

Apart from perhaps ArchiCAD and Google SketchUp, which are convivial for EDP work, all the programs reviewed are more suited for detailed design than EDP. This review also outlines the fact that a direct explicit feedback about passive solar gains (linked to changes made on architectural parameters) is still lacking in most CAAD programs but that the recent advances in this field in CAAD-BIM applications are promising.

4.1.2 Overview of available CAAD software for estimation of daylighting and daylight utilization

This review also indicated that most CAAD software include some features for the prediction or visualization of daylighting. Amongst the CAAD tools, the BIM applications offer many possibilities for daylight analyses. For example, MicroStation via the Bentley Hevacomp and Bentley Tas simulator make it possible to perform daylight analyses; Revit performs daylighting analyses using the IES VE-Ware plugin (which uses Radiance) and Revit is also compatible with Ecotect; Vectorworks is interoperable with IES VE and Ecotect, etc.

Moreover, most of the non-BIM CAAD software reviewed also allow some form of daylight analysis and/or visualization. For example, AutoCAD creates .dwg files which can be read by most lighting and simulation software e.g. Ecotect, Radiance, etc.; Blender allows adding a plugin called b/rad, which is a Blender-based user interface for Radiance; 3ds Max Design 2010 features the Exposure technology to conduct validation studies based on the Radiance engine; Google SketchUp performs daylighting analyses using the IES VE-Ware or OpenStudio plugin, etc.
Many CAAD software do not provide *quantitative* daylighting calculations, but perform rendering based on the real behaviour of light. These software (ArchiCAD (VBE), AutoCAD, Blender, Caddie Vio (Lightworks), CINEMA 4D, Digital Project, form•Z (RenderZone), Houdini, Lightworks, Maya (Mental Ray), Rhinoceros 3D (Flamingo, Penguin), Vectorworks (RenderWorks), and 3ds Max) may be used to generate a *qualitative,* physically-based evaluation of daylighting in a project. However, the estimation of real daylight utilization (energy savings by replacement of electric light by daylight) is not explicit with most CAAD programs reviewed. All software which perform physically-based rendering also include the Global Illumination algorithm in rendering options that allows performing more realistic lighting results. Note that in most cases,

3D rendering does not support EDP design decisions because it requires a completed model of the building with detailed optical properties.

4.1.3 Overview of available CAAD software for sizing PV and ST systems

Amongst the CAAD tools reviewed, Allplan and DDS-CAD are explicitly developed for sizing photovoltaics (PV) and/or solar thermal (ST) systems. Also, since EnergyPlus allows the simulation of active solar components for sizing PV and ST systems, all CAAD programs that are linked with EnergyPlus allow active solar systems calculation, such as ArchiCAD, DesignBuilder, Google SketchUp (OpenStudio plugin), Microstation (via Hevacomp, an interface to EnergyPlus). Note that Energyplus includes a detailed PV and Solar collector library. EnergyPlus also features on-site PV inverter and storage systems in addition to ST hot water systems.

Note that, apart from Google SketchUp, which is often used at EDP, all the CAAD tools listed above are more suited for detailed design than EDP. Even the Google SketchUp active solar calculation environment is used more as a post-design rather than a design tool since the calculations are performed within OpenStudio (EnergyPlus interface).

4.2 Visualization tools

This review outlines the fact that none of the visualization tools reviewed include solar calculations in terms of passive solar gains prediction or design of active solar systems. Most tools reviewed are focused only on visualization of electric light and/or daylight effects, which was an expected result.

4.2.1 Overview of available visualization software for estimation of daylighting and daylight utilization

Since the main goal of visualisation software is to provide visualization for light-matter interactions, most of the applications reviewed include advanced or very advanced algorithms for the simulation of light. However, it is not always clear whether the calculations are “cosmetic” or governed by the natural laws of illumination. Only one program (LuxRender) explicitly allows choosing between biased (speed) and unbiased (physically-based) rendering. In many software (Flamingo, Kerkythea, LuxRender, Maxwell Render, RenderZone, V-Ray, YafaRay), the approach to rendering is based on the physical laws of illumination.

Generally, the visualization software do not provide technical solar calculations but most of these programs can be used to study direct and/or diffuse light penetration patterns and shading effects on building facades and inside buildings, at one specific moment or for a sequence in time. Few visualization programs provide *numerical* output of light intensity results; the focus is clearly on visualization rather than numerical analysis. In most cases, 3D rendering does not support EDP design decisions; rendering is thought of as a post-design rather than a design tool. A few visualization software (LightWave, LuxRender) include detailed algorithms for the simulation of electric lighting effects by using .ies lighting files. Finally, only LuxRender uses full spectral colors, instead of limited color channels (e.g. RGB i.e. red, green, blue), for the prediction of emitted and reflected surface colors which is a promising development for future study of special coating and/or glazing materials widely used in solar architecture.

4.2.2 Overview of available visualization software for the visualization of active solar components

Finally, the review indicates that none of the visualization tools reviewed explicitly supports the design of PV and/or ST systems. This is certainly an area which needs much development in the future. However, a company called ISAAC recently developed a parametric and customizable 3D

CAD object to facilitate and stimulate the use of BiPV (building integrated photovoltaic) systems by architects and designers and to improve the architectural quality of BiPV systems. The CAD object, which is still a prototype, can be used with both ArchiCAD and AutoCAD, two widely used modeling tools compatible with most of the visualization tools mentioned in this review.

4.3 Simulation tools

4.3.1 Overview of available simulation software for the prediction of passive solar gains

This review indicates that there are many simulation software which can be used for the prediction of passive solar gains. In most cases, the estimation of passive solar gains is considered in the calculation of the whole-building thermal balance calculation. Simulation applications which include passive solar gains calculation are: bSol, DesignBuilder, DPV (Design Performance Viewer), Ecotect, EDG II, BKI ENERGIEplaner, eQUEST, IDA ICE, IES VE, LESOSAI, VisualDOE.

bSol, EDG II and LESOSAI do not support a 3D environment and thus offer limited potential for the development of architectural design aspects. A higher understanding of the building is required for these software, because the user has to describe the architectural parameters (shape, orientation, opening, etc.) in terms of data-entry and numerical input. However, LESOSAI 7.0 will have a wizard 3D in September 2010 and allow import of 3D Google SketchUp before the end of 2010.

Among the other software listed above, DPV is probably the most suited for EDP because it is imbedded in the BIM-application Revit. Moreover, note that VisualDOE may also be used at EDP.

4.3.2 Overview of available simulation software for estimation of daylight utilization

Although there are many software used for the estimation of daylighting and daylight availability, only a few are really designed for the estimation of daylight which will replace electric lights and provide energy savings. The simulation software with the most interesting physically-based numerical daylight calculations are: DAYSIM, DesignBuilder, Ecotect, eQUEST, IDA ICE, IES VE and Radiance.

Radiance is probably the most accurate and validated light/daylight simulation engine and it is used by many other software: DAYSIM, IES VE, 3ds Max, Blender via b/rad, etc. However, Radiance is not suitable for EDP, when much information about the building is missing. DesignBuilder, Ecotect and IES VE are probably more suitable for EDP work on daylighting aspects.

4.3.3 Overview of available simulation software for sizing PV and ST systems

The simulation software with the most interesting active solar systems' features are Ecotect, BKI ENERGIEplaner, eQUEST, IDA ICE, LESOSAI, Polysun, PV*SOL, PVsyst, T*Sol, and VisualDOE. Note that two of them, BKI ENERGIEplaner and LESOSAI, support active solar systems predictions based on the Polysun technology.

Note that PV*SOL, and T*Sol do not support a 3D environment and thus offer limited interest for architects. Since the user has to describe the configuration of the building in terms of data-entry and numerical input, a higher understanding of the building is required for these software.

Among the software listed above, Polysun may be used at EDP for the prediction of systems profit ratio, PVsyst offers a preliminary design level, and T*Sol can be used at any stage. All other applications are more suited for detailed design than EDP. Additionally, the review indicates that simulation software are not really suitable for the architectural *integration* (development of architectural design) of solar active systems because visualization and 3D environment are not sufficiently developed, even if they provide an EDP design level (e.g. PVsyst).

5. Conclusion

As part of the work achieved within IEA Task 41 Solar Energy and Architecture, Subtask B on Methods and Tools for Solar Design, this paper presented a review of computer tools widely used by architects today. The review covered a total of 56 programs in three categories: CAAD, visualization and simulation software. The main conclusions from this review are stated below:

- **Lack of advanced solar tools supporting EDP work.** Few software allow evaluating EDP decisions in relation to solar aspects. EDP is a highly intuitive, iterative process, which requires changes on the building overall volume, geometry, orientation, etc. An appropriate EDP tool should allow changes on these parameters with a mouse click and the architect should have direct, explicit feedbacks related to solar aspects including passive solar gains, daylight utilization and active solar systems performance. Since, in theory, BIM-applications are created to support the whole design process, they offer the greatest potential to optimize the utilization of passive and active systems, as well as their architectural integration. However, BIM-software are not actually suited for EDP work. Google SketchUp probably offers the greatest potential as a tool for EDP and the recent energy plugins created for Google SketchUp are promising advances in this field.
- **Systemic specialization of available software.** Many software are specialized in one type of system (for example PV or ST). Since the goal of high quality solar architecture is to achieve a good balance of passive and active solar utilization (including daylight utilization) by an adequate design of the building envelope, this is a major hinder.
- **Lack of clear numerical feedback yielding informed decisions.** Solar functions are popular features in software. Generally, this feature investigates and shows the impact of sunlight and shadows on the project. However, an iterative,numeric, and direct feedback showing *quantities* of solar energy incident on the building is rarely available. Also, most programs only show solar radiation *incident* on the building rather than solar gains through windows or the amount of natural light usable inside the building.
- **Lack of clear indication about physically based models in rendering options.** In many CAAD and visualisation software, rendering is based on "cosmetic" algorithms rather than physical laws. This may not only yield errors in interpretation from the part of the architect, it does not support development of real solar design as part of an integrated design process. The programs should at least state clearly whether the algorithms are based on physical laws of illumination or not.
- **Lack of CAAD tools supporting architectural integration and sizing of active solar systems.** Active solar systems sizing is mostly supported by specialized simulation software, which generally offer simplistic and limited 3D interface. To achieve an architectural integration of PV or ST to the building envelope, architects need to "see" and customize the active solar components directly in their building model. However, the 3D CAD PV object developed by ISAAC is really promising although its utilisation is currently limited to ArchiCAD and AutoCAD.

Generally, this review indicates that architects do not yet have the tools for feeding an iterative design process including solar aspects with correct figures and prediction algorithms including all aspects of solar energy i.e. passive solar gains, daylight utilisation and energy production through active solar systems. However, the review also outlines that the recent developments in building information models (BIM) have permitted to come closer to this goal and many architectural design software available today actually include some form of energy evaluations, which was unthinkable only ten years ago.

6. Limitations and wild cards

The review covers a large number of tools widely known and used by the architectural community. However, a comprehensive review of all available tools in the world is nearly impossible due to the amount of information which must be collected. This review is thus wide but still incomplete. Most of the information provided in the report has been retrieved from the official websites of each software provider. This information tends to be tendentious and ameliorates the performance, user-friendliness, compatibility or scope of application of the tools that each provider presents. However, information has often been tempered by the knowledge and experience of authors. A further step in the present work could be to test the programs using a reference model and/or ask users if they agree with the facts presented in this report.

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