Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 118 (2015) 774 – 780

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Sustainable Design, Engineering and Construction

Evaluation of performance modelling: optimizing simulation tools to stages of architectural design

Massih Nilforoushan Hamedani [a]*, Ryan E Smith [b]

[a]: *School of Architecture, University of Utah, Integrated Technology in Architecture Center (ITAC)*
University of Utah, College of Architecture + Planning, 375 S. 1530 E. RM 235, Salt Lake City, Utah, 84112, USA
[b]: *Associate Professor, School of Architecture, University of Utah, Integrated Technology in Architecture Center (ITAC)*
University of Utah, College of Architecture + Planning, 375 S. 1530 E. RM 235, Salt Lake City, Utah, 84112, USA

Abstract

Given the necessity of resilience architecture is vital, the most effective decisions on building performance are made at design stages. Simulation represents a possible solution to the complex problem of enabling comprehensive and integrated appraisals of design options under realistic operation conditions [1]. Building Energy Performance Simulation tools (BEPS) provide an opportunity for architects to assess their design strategies in order to reach a high performance building. According to the current developments of Building Information Modeling (BIM) as an Integrated Project Delivery (IPD) tool this study tries to define a logical relation between level of development in different stages of architectural design and BEPS tools in order to fill the gap between architects and engineers in earlier stages of building design. In order to assess the current capability of the simulation tools and evaluate their platforms as an Integration of tools in building design decision making by defined criteria of Input data required for simulation, Usability and graphical visualization of the interface, Interoperability of building modelling, Accuracy and ability to simulate detailed and complex building components. In order to have a market assessment of these types of building performance tools, a survey was conducted of architectural and engineering firms of diverse size.

Peer-review under responsibility of organizing committee of the International Conference on Sustainable Design, Engineering and Construction 2015

Keywords: Building energy performance simulation; Building information modeling; Level of development; Design decision support

Peer-review under responsibility of organizing committee of the International Conference on Sustainable Design, Engineering and Construction 2015
doi:10.1016/j.proeng.2015.08.513

1. Introduction

Buildings account for approximately 50% of total U.S. energy consumption and CO_2 emissions, and as such represent a key target for efficiency improvements [2]. To reduce the total energy consumption and CO_2 emissions, industry and governments initiatives have catalyzed the energy efficient building design with different rating systems and high energy performance regulations such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system [3], the Centre for Energy and the Environment in the UK, where develop an environmental assessment and rating system for building (BREEAM) [4], ASHRAE Standard 189.1 for the Design of Green, High Performance Buildings [5], and the International Code Council developed the International Green Construction Code (IgCC) [6]. Although these standards and rating systems have reduced energy consumption and CO_2 emission in construction sector, architects and engineers can design more efficient buildings via current enhancements of building project delivery method and building performance simulation tools.

New improvements of building energy modelling platforms and capabilities of Building Information Modelling (BIM) actuate architects and engineers to assess their design, however, building energy performance simulation still has a low impact in the building design sector, especially in design decision making in earlier stages of design.

The aim of this paper is to support architects and engineers to design energy efficient buildings by implementing appropriate building energy performance analysis platforms in different stages of architectural design to make proper design decisions.

2. Building Information Modeling (BIM) and Level of Development (LOD)

The American Institute of Architects (AIA) developed definitions for LOD specification in *AIA G202-2013 Building Information Modelling Protocol Form* [7]. The document describes and illustrates characteristics of model elements of different building systems at different Levels of Development. This clear articulation allows model authors to define standards for development, and allows downstream users to clearly understand the usability and the limitations of models they are receiving. The specification will help AEC industry to have a standardized framework as a more useful communication tool and aid individual project stakeholders in digital workflow.

2.1. Fundamental LOD definitions

AIA defines Level of Development as the description of the minimum dimensional, spatial, quantitative, qualitative, and other data included in a model element to support the authorized uses associated with such LOD [7]. Each model element develops at a different rate. The Level of Development (LOD) framework allows the project participants to understand the progression of a model element from conceptual idea to precise definition and description. Table 1. charts specifications of different LODs based on AIA definitions of design stages by numerical codes.

Table 1. AIA level of development specification

BIM Phases	Specifications
LOD 100	The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.
LOD 200	The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 300	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 350	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.
LOD 400	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.
LOD 500	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements

Table 1 illustrates the approximate size, shape, location and orientation of the project as determined in LOD 200 and in specified in LOD 300. Major optimization and energy efficiency design decision are identified in LOD 200 such as:

- Building orientation
- Building layout and form
- Geometry, position and density of fenestration
- Building envelope and fabric construction
- Daylight performance and solar gain and shading strategies
- Natural ventilation strategies

2.2. Energy efficient decisions in early stages of design

Level of effectiveness in design decisions in LOD 200 and LOD 300 are envisioned and outlined by Eddy Krygiel in Green BIM [8]. The article compares different simulation scenario results of a 50,000 square foot open office building type in Seattle, Washington. The scenario runs vary by building orientation, solar strategies, building masses and forms. Table 2 charts seven simulated orientation scenarios of the office building and energy use of the building in each case.

Table 2 Simulation percentage of energy efficiency gained for different orientation and solar strategies for five-story, 50.000 square feet office building in Seattle using Autodesk Ecotect Analysis [8].

	Orientation		**Orientation + Shading**		**Orientation + Shading + Daylighting**	
Rotation from true south	Energy use KBtu/sf.year	Annual operation cost saving (over base case)	Energy use KBtu/sf.year	Annual operation cost saving (over base case)	Energy use KBtu/sf.year	Annual operation cost saving (over base case)
90º W	61.9	Base case	57.1	6.39%	54.4	15.24%
45º W	62.1	0%	56.5	6.84%	53.8	15.7%
15º W	60.9	0.9%	56.6	6.89%	52.3	18.27%
0º	61.2	0.7%	56.7	6.84%	52.3	18.27%
15º E	60.7	1.3%	55.7	7.9%	51.7	18.89%
30º E	61.5	0.7%	56.3	7.30%	52.1	18.33%
45º E	61.7	0.5%	56.3	7.15%	52.2	18.03%

Table 2 demonstrates that an appropriate design decision in the LOD 200 can reduce 19% energy consumption of a building. BIM provides easier format to exchange models between different platforms (modelling tools and energy performance tools). However, whole building energy simulation tools such as IES/VE, eQuest and DOE-2 still require more detailed development of the project than LOD 200 as input data to simulate an appropriate assessment in order to provide holistic energy/cost calculation of a building in early stages of design.

3. Building energy performance tools selection

To investigate the gap of using energy simulation tools as design decision-making tool, this study by the authors suggests a set of four major selection criteria for building energy performance tools based on ongoing discussions in building simulation communities;

- Input data required for simulation
- Usability, graphical visualization and interface
- Interoperability of building modelling
- Accuracy and ability to simulate detailed and complex building forms and components

3.1. Input data required for simulation

Building energy performance platforms require fundamental information to simulate the energy consumption of a building. However, level of development of this information varies based on different platforms and the simulation's level of detail. Generally, tools require more advanced developed inputs than LOD 200, which makes them inappropriate as design decision-making tool in LOD 200.

3.2. Usability, graphical visualization and interface

The usability and graphical features of the interface is a fundamental selection criterion of a building energy performance tool. It includes the functionality of a tool, graphical representation of the inputs and results of the simulation platforms. Features such as comparative reports, benchmarking and graphical customization capability of tools are important for architects.

3.3. Interoperability of building modelling

Interoperability of building modelling that corresponds to the ability to manage and communicate building data between collaborating firms and within individual companies design and construction. This is a fundamental criterion for assessing building energy performance simulation tools because it allows multidisciplinary storing and sharing of information with one virtual representation [9].

3.4. Accuracy and ability to simulate detailed and complex building forms and components

Accuracy is a fundamental criterion of an energy simulation tools. Analytical and empirical verification and calibration of building energy performance simulation tools have direct impact on tools liability and level of quality. Further consideration is the ability to model and simulate complex building components and forms. For example, consider the difficulty of high-resolution simulation requirements of a double skin façade along chilled beams and recovery ventilation system in a complex geometrical mass.

3.4.1. Case Study Building

A preliminary evaluation of energy simulation tools was conducted for a two story, two bedroom, 1100 square feet residential building designed at University of Utah called [X14] house for a potential site in Denver,

Colorado. The building was designed with passive strategies with the main goal to meet Passive House Institute US (PHIUS) standard. The building design incorporated several advanced methods via energy simulation tools, Passive House Planning Package (PHPP), Autodesk Ecotect and Sefaira. The PHPP is a spreadsheet based design tool aimed at architects and designers to assist the design of Passivhaus standard. The downside is that data input is somewhat tedious, and there is no direct CAD software interoperable link as yet. PHPP requires high level of detail and were used to evaluate the design in later stages of design. The modeling of the [X14] began by modeling its geometry in Ecotect, as seen in Figure 1. Then, inputs for building's occupancy patterns, systems, equipment, lighting and plug loads were specified. In order to have energy simulation based on Sefaira output, the Ecotect model was imported into SketchUp. Building components (i.e. walls, floors, roofs, partition walls, shadings and glazing) assigned as entities using the Sefaira Plugin for SketchUp. Figure 2. shows the evaluation of the model from SketchUp to energy analysis results.

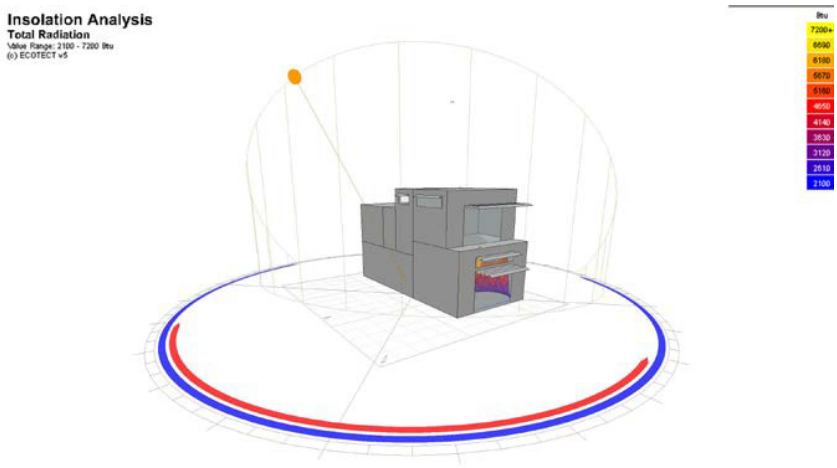

Fig 1. Energy model in Autodesk Ecotect

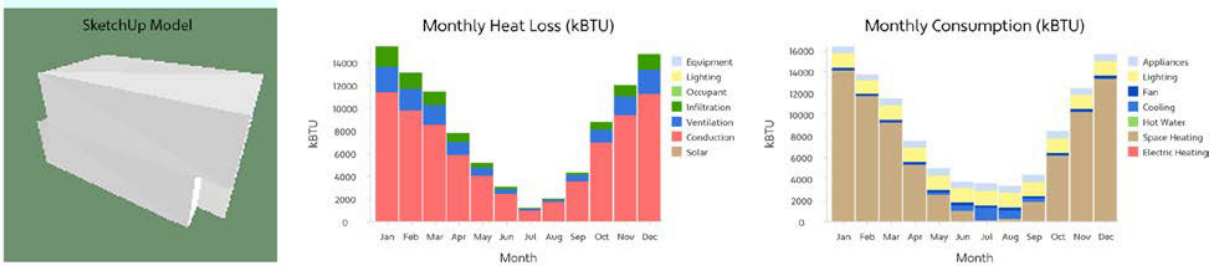

Fig 2. Energy model in Autodesk Sefaira

Calibration of these three energy models based on actual energy usage of the house can define each tool level of accuracy. But the house is not occupied and it is not possible to evaluate the models based on actual energy performance. It is crucial to understand the limitations of different tools in order to successfully integrate building performance analysis in early stages of the design process. Table 3. demonstrates simulations results, inputs data level of detail and Energy Use Intensity (EUI) of each simulation models.

Tool	**Inputs level of development**	**Energy Use Intensity** (KBtu/sf.year)	**Modeling limitation of energy simulation tool**
Autodesk Ecotect	LOD 300	39	It has user friendly interface and ability to run comprehensive solar and shading simulations, but it is not possible to make comparison cases.
PHPP	LOD 300 - LOD 350	32	It is not possible to 3D model or import/export a BIM based model. There is no graphical representation of results. It is an accurate tool to evaluate passive residential building's thermal characteristics.
Sefaira	LOD 100 – LOD 200	27	Sefaira cannot simulate models with more than 3000 components and 1000 glazing parts using Revit and SketchUp plug in. Input level of detail makes it a user friendly tool for earlier stages of design but inaccurate tool for detailed energy performance simulations.

4. Conclusion

Building energy performance simulation tools can accurately quantify energy consumption of a building, using developed specifications of the building design. These tools are not accommodating in the early stages of architectural design. This paper represents the importance of decisions making in early stages of building design development, since major parameters of the building are determined in LOD 200. These parameters include building orientation, building form and fenestration properties. In addition, designers' expectations from an energy simulator as a design decision-making tool need to match the energy analysis tools selection criteria. As the next step in this study, the authors will test the validity of the literature review through a survey of simulation tool users (including architects, engineers) in medium size and small size firms. This survey is intended to evaluate the four selection criteria of required input data, usability, interoperability, and accuracy across different simulation platforms. This is to determine the appropriate stage of design for simulation methods. The final results of the questionnaire and simulations can support and accelerate software developers to design applicable building energy performance simulator for earlier stages of design.

References

[1] Clarke, J. A. Energy Simulation in Building Design. 2nd ed. Oxford: Butterworth-Heineman, 2001
[2] EIA. Annual energy review 2010. In: U.S. Energy information administration 2000; 2010. DOE/EIA0384.
[3] "About | U.S. Green Building Council." About | U.S. Green Building Council. [Accessed January 4, 2015]. http://www.usgbc.org/About.
[4] "BREEAM: What Is BREEAM?" BREEAM: What Is BREEAM? [Accessed January 4, 2015]. http://www.breeam.org/about.jsp?id=66.
[5] ASHRAE standard 189.1-2009. Atlanta, GA: American Society of Heating, Refrigeration, and Air-Conditioning Engineers; 2009.
[6] "International Green Construction Code." International Green Construction Code. [Accessed January 5, 2015]. http://www.iccsafe.org/cs/igcc/pages/default.aspx?usertoken={token}&Site=icc.
[7] AIA Document G202™–2013, Project Building Information Modeling Protocol Form
[8] Krygiel, Eddy, and Brad Nies. Green BIM: Successful Sustainable Design with Building Information Modeling. Indianapolis, Ind.: Wiley Pub., 2008.
[9] Attia, Shady, Jan L.m. Hensen, Liliana Beltrán, and André De Herde. "Selection Criteria for Building Performance Simulation Tools: Contrasting Architects' and Engineers' Needs." Journal of Building Performance Simulation, 2011, 1-15.
[10] Attia, Shady, Elisabeth Gratia, André De Herde, and Jan L.m. Hensen. "Simulation-based Decision Support Tool for Early Stages of Zero-energy Building Design." Energy and Buildings: 2-15.
[11] Hygh, Janelle S., Joseph F. Decarolis, David B. Hill, and S. Ranji Ranjithan. "Multivariate Regression as an Energy Assessment Tool in Early Building Design." Building and Environment: 165-75.

[12] Souza, Clarice Bleil De. "Studies into the Use of Building Thermal Physics to Inform Design Decision Making." Automation in Construction: 81-93.
[13] Hensen, Jan. Building Performance Simulation for Design and Operation. Abingdon, Oxon: Spon Press, 2011.
[14] Deutsch, Randy. BIM and Integrated Design Strategies for Architectural Practice. Hoboken, N.J.: Wiley, 2011.
[15] Wang, Q., and K.l. Poh. "A Survey of Integrated Decision Analysis in Energy and Environmental Modeling." Energy.
[16] Jeong, Woonseong, Jong Bum Kim, Mark J. Clayton, Jeff S. Haberl, and Wei Yan. "Translating Building Information Modeling to Building Energy Modeling Using Model View Definition." The Scientific World Journal: 1-21.
[17] Pohekar, S.D., and M. Ramachandran. "Application of Multi-criteria Decision Making Tosustainable Energy Planning — a Review." Fuel and Energy Abstracts, 2004, 343-44.