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Enhancing energy efficiency in residential buildings through the use of BIM: The case for embedding parameters during design

Scott F. Beazley
*University of Wollongong, sbeazley@uow.edu.au*

Emma Elizabeth Heffernan
*University of Wollongong, eheffern@uow.edu.au*

Timothy J. McCarthy
*University of Wollongong, timmc@uow.edu.au*

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Scott Beazley\textsuperscript{a,*}, Emma Heffernan\textsuperscript{a}, Timothy J McCarthy\textsuperscript{a}

\textsuperscript{a} ARC Steel Research Hub/Sustainable Buildings Research Centre, University of Wollongong, NSW 2522, Australia

Abstract

A building design is typically created by a collaboration of professionals. Whilst the advent of BIM tools makes the assessment of the performance of an iterative design possible, these tools are not commonly used, due to traditional practice prevailing, technical limitations including differing data formats, and industry resistance to innovation. Timely consistent feedback throughout the design process, as major design decisions are made, could enable the enhancement of energy efficiency. However, current design guidelines are typically not in digital rule form, preventing the automated checking and validation of developing design models. Furthermore, architectural design tools have poor connections to thermal and environmental analysis software, which is exacerbated by a lack of knowledge of the data requirements of other disciplines both upstream and downstream. This paper explores the potential for embedding parameters within architectural model files to enable the enhancement of energy efficiency at the design stage and through the design process. It explores the architectural to energy analysis data exchanges, and demonstrates the way in which energy efficiency parameters can be embedded within model files to inform decision making at the conceptual design stage. The paper found that by using tools readily available, it is possible to add value during the design process through the use of BIM, with improved design outcomes as the result. The need to develop new workflows between the disciplines as a result of this different approach was highlighted. This enhanced practice is more responsive and can support better communication within project teams through providing timely information and feedback, providing analysis before optimisation for energy efficiency.

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* Corresponding author. Tel.: +61-401-024-971
E-mail address: sbeazley@uow.edu.au
1. Introduction

Globally, buildings are responsible for over one third of final energy consumption and the greenhouse gas emissions related to the generation of that energy [1]. It has been asserted that it is simpler to save energy than to produce it [2], thus, the importance of ensuring the energy efficiency of buildings for a range of reasons is now well established. Energy efficiency, or passive design measures are employed to minimise the energy consumption of a building relating to thermal comfort, lighting, vertical transportation, and hot water. With the aim of delivering a desired level of energy efficiency, energy simulation tools are now commonly used within the building design process in order to predict the energy required to provide internal environmental comfort.

In addition to the move to deliver energy efficient buildings, the methods used within the design process have also been changing, from paper or 2D Computer Aided Design (CAD) to Building Information Modelling (BIM). The use of BIM can offer many benefits including: improved accuracy, time savings, more rigorous design and analysis processes, and the ability to predict environmental and lifecycle performance [3]. However, interoperability between BIM and energy simulation tools is currently problematic [4], often resulting in architects designing a building in one model and an energy consultant reproducing that design within a Building Energy Model (BEM) [5]. Project collaboration is necessary to integrate passive design principles as they impact a large number of interrelated building parameters, which are dealt with by a range of building professionals. Traditionally this process has not been efficient from the exchange of discipline input, especially geometry. Major decisions that influence energy efficiency are made in concept design phase when little information is available, and often before collaboration with specialists is possible [6]. It is therefore necessary to improve the integration of energy simulation tools with the design process. Digital workflows have significant potential to assist in this integration.

The aim of this paper is to explore ways in which both energy and spatial parameters can be embedded within model files to enable varying levels of analysis to be undertaken at various design stages, and thus inform the iterative design decision making process. The paper is structured as follows: Section 2 presents the current constraints in terms of BIM and energy assessment interoperability, Section 3 then illustrates examples of model content specifications for digital exchange, before model parameter placement is demonstrated in Section 4, and the potential for implementation in Australia is discussed in Section 5. Finally the paper concludes in Section 6.

2. Current problems

2.1. Lack of model content specification clarity

The building design process can include a number of disciplines that jointly create a ‘building database’. Each requires information such as geometry and building element data from the other to complete their work. Current practice mutually excludes Architects from early stage energy evaluations of their building designs and building services engineers from the geometric design process their energy evaluations could inform [7]. Thus there is at least a need for smooth communication and data exchange between the disciplines. Building design analyses used to inform energy efficiency have particular requirements of building geometry and data. Architects rarely create the type of “air-tight” models that engineers require for thermal analysis, as they are unaware of issues for engineers, do not see it as their task to model for those purposes, or have never done that previously. Their models are often ‘heavy’ in size, having too much geometric detail, even at early design phases, for energy analysis and can overload analysis software. So engineers start all over again, to create appropriate stripped down geometry for their own purposes. In this case, project collaboration is not taking advantage of digital exchange possibilities, so creating a duplication of 3D geometries by different disciplines, due to poor upstream information that has been provided, or lack of knowledge of their discipline requirements [5]. This duplication can lead to errors of data transfer, multiple databases of what should be the same information, not supporting a single source of data. Furthermore, this lack of integration fails to support an iterative design process which could help to connect the energy performance with the geometric design, ultimately improving the performance of the building [7]. Some of the project data required for early phase energy analysis is easy to define and communicate, such as: site information, weather data, climate zone, building usage and assumed occupancy schedule. Other data can be more complex, uncertain or ambiguous such as:
building form, building material physical properties, internal layout, and thermal zoning. Interpreting these from early project information is often unreliable and cumbersome, as they are often part of the iterative process.

2.2. Interdependence of responsibility

Another complication is the interdependence of the physical properties of building elements, such as walls, which are often dealt with independently by separate discipline consultants, and can potentially be in conflict. These potentially conflicting properties include: R-value, acoustic rating, fire rating and compartmentation, structural usage, and reflectivity. At some point, the project manager has to make the appropriate selection to satisfy all requirements.

2.3. Lack of digital regulation and assessment tools

Current mandatory legislation and design guidelines in Australia, such as the National Construction Code (NCC), Building Code of Australia (BCA) and the New South Wales Apartment Design Guide (ADG) are not in digital rule form, thus preventing the automated checking and validation of developing design models for necessary properties and parameter values. Manual assessment of building designs is time consuming and potentially imprecise, and without the ability to automatically reassess an amended design. Digital workflows could enhance and change the nature of this collaboration and assessment process.

3. Examples of model content specifications for digital exchanges

3.1. General Services Administration

In 2003, the General Services Administration-Public Buildings Service from the USA, established the ‘National 3D-4D BIM Program’ which contained a long term strategy for the implementation of BIM for their portfolio of assets [8], [9]. This initiative, from a significant client, has helped to guide the development of industry software and it is now widely used by design and construction professionals. At present there are eight GSA Building Information Modelling guides. One output from this program is the GSA Building Information Modelling Guide Series 05 – Energy Performance [10] which defines phases and data required for analysis for energy efficiency:

- Preliminary Concept Design (Phase 4)
  - Content: Site location, building orientation, massing, and default assumptions
  - Purpose: Quickly assess large-scale impacts of design alternatives
- Final Concept Design (Phase 5)
  - Content: Building geometry, preliminary layout, construction, mechanical equipment, and intermediate assumptions
  - Purpose: Evaluate and compare proposed design schemes, intermediate analysis, preliminary code compliance
- Design Development (Phase 6)
  - Content: Building geometry, detailed layout, detailed construction and envelope design, mechanical equipment, building controls, and detailed assumptions
  - Purpose: Estimate final design energy performance, detailed analysis, preliminary code compliance

The above descriptions provide general intent, but there is a need to define more precisely the content of building models concerning the types of objects, their parameters and range of values required at each phase.

3.2. BuildingSMART International

BuildingSMART International, formerly the International Alliance for Interoperability was established in 1994 to address the lack of interoperability of building and construction software. One aspect of their work has been to define data exchanges at different project phases for specific purposes. These are called Information Delivery Manuals (IDM), based on Model View Definitions (MVD). For energy analysis, the IDM for BIM Based Energy
Analysis has two main parts: process map, and exchange requirement. The process map defines the overview of the data exchange process and the model content. This is described in a Business Process Mapping Notation diagram.

The exchange requirement defines the explicit model objects and parameters necessary. These definitions allow the automated checking of model data for being present or not, and its value. The IDM recognises the iterative nature of energy analysis and addresses both the conceptual and detailed design phases with increasing precision of input and outputs.


- The site and building location
- Weather data
- The building orientation including its relationship to true north
- The site and building elevation above a reference datum
- The building storey information
- Building usage
- 3D geometry of adjacent buildings
- 3D geometry of the building, including walls (exterior/interior), curtain walls, roofs, floors/slabs, ceilings, windows/skylights, doors, and shading devices. (Detailed specific parameters of these objects are also a requirement).
- Classification, construction type and material of the above building elements
- Space objects, including those defined by virtual space boundaries

![Figure 1: Space/Room objects in Autodesk Revit model](image)

Figure 1: Space/Room objects in Autodesk Revit model

Figure 1 shows the analytical surfaces of Spaces/Rooms available to export to energy analysis software. Each Space/Room can be examined for gaps that will impede energy analysis [12], [13]. Figure 2 illustrates the analytic properties of the selected wall object, displaying values from the architect ready for energy analysis.
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Figure 1: Space/Room objects in Autodesk Revit model

3.3. Automated model checking potential: overseas examples

The IDM’s more precise and detailed specification for content, if implemented in building models, provides the basis for checking model construction in a computer automated process. Model checking software is able to check for the following: the presence of object parameters and their values within defined ranges; compartmentation for thermal zoning and/or fire safety; site data; spatial accuracy; rooms/spaces correctly formed using defined room bounding objects; model building objects created by correct BIM tool; and building systems such as floors, walls, ceilings, and roofs. This quality checking capability has been implemented in a small number of countries including Finland and Norway. The Finnish COBIM standards [14], [15] can be checked in Solibri Model Checker by customised rulesets, where the whole legislative requirements are collated. Some criteria still have to be manually checked, but object geometry, data and some relationships can be checked. Some rulesets need to be custom parameterised for each project.

Six checklists have been defined for the “Starting Situation BIM”, “Architectural BIM”, “Structural BIM”, “Electrical BIM”, “HVAC BIM”, and “Merged BIM” models. These align with national building regulations in Finland. An example outline is shown in Figure 3.

Figure 3: COBIM Architectural ruleset example in Solibri Model Checker
3.4. Automated model checking: Australian opportunities

The National Digital Modelling Guidelines [16], discussed potential benefits of BIM for the Australian industry of: model setup, model checking and auditing, and the value of IDM. These benefits could extend to addressing similar energy efficiency model checking rulesets as in COBIM, for Australian building regulations. Especially building element properties such as R-value values, specified in Section J of the NCC - Energy Efficiency. This would aid the design and analysis workflow in a more frequent iterative process, leading to optimisation of the building design and product selection.

Building system elements are often systems made up of a number of layers that each have an R-value and when combined have an aggregated system total R-value. This aggregation is supported in BIM software, by default settings and also more detailed definitions.

Section J-Energy Efficiency stipulates a number of requirements. These can be defined and embedded in a model and include: occupancy and room thermal performance, minimum R-value for building systems, glazing performance based on orientation, areas, design vs. actual or calculated values.

Customised Australian rulesets could thus be set in Solibri Model Checker.

4. Model parameter placement

Model creation software has default values for building elements, which are built-up from a number of layers for walls, floors and roofs. For example, in Autodesk Revit, analytic construction properties can be customised within objects, to match locally available materials. Thermal conductivity, specific heat, density, emissivity, permeability, porosity, reflectivity and electrical resistivity properties are available to adjust for specific chosen materials (Figure 4). These materials are then assigned to each layer of system objects like walls, floors and roofs, which are aggregated to provide the overall performance.

![Image](image_url)

**Figure 4:** Autodesk Revit customised thermal wall properties for detailed analysis
There are current limitations due to reliance on the Autodesk Materials database which is USA based. Data of local Australian materials is not in the default database, but can be customised. Building material manufacturers supply technical support information for their products, and their BIM objects can contain this level of property detail.

5. Implementation in the Australian context

Within the Australian context, a number of constraints currently inhibit the integration and automation of energy assessment within BIM.

The energy efficiency requirements in Section J of the NCC, are not in digital form based upon parametric properties, that can be used in automated computer assessment. There is also a lack of Australian model checking rulesets that specifically address local building codes and regulations.

A recognised classification system of building elements for automated exchanges and use of digital models, is necessary to be able to better deal with the increasing amount of building data. The USA, for example, has OmniClass Construction Classification System for the construction industry [17]. It encompasses a number of different classification types. For example: Table 11-Construction Entities by Function, Table 13-Spaces by Form, Table 21-Elements, Table 23-Products, Table 31-Project Phases, Table 41-Materials, Table 49-Properties. The UK has the UniClass 2015 series of classification tables, but Australia has no equivalent comprehensive set of classifications.

BIM software has a range of file interoperability issues. Currently IFC (Industry Foundation Class) [18] files are the most commonly supported format, although there are still some modelled objects that are not easily exported, or their data is not accessible. The latest IFC4 release, which has extended capabilities, is not supported fully by many of the current BIM software. Australian standards need to be established for optimised industry workflows.

6. Conclusion

The application of current industry BIM tools, with enhanced digital workflows in architectural modelling, for the embedding of parameters to the data exchanges for thermal analysis, would provide greater transparency of design intent and address co-ordination issues. Better informed design decisions would be possible that could result in the rapid iterative comparison of design options, greater continuity of project data throughout project phases, and less chance of duplication in design effort to enhance the energy efficiency of residential buildings.

There are a number of BIM implementations from around the world that can be used to guide development of Australian BIM use, especially from GSA in the USA, and COBIM in Finland. The energy efficiency provisions of Section J of the Australian building codes could be incorporated in software and rule based design tools. Associated documented digital workflows, using checking and auditing of digital models, are needed to support the uptake of BIM by industry, with customised Australian object materials.

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