Pathways for Testing Environmental Building Performance

Comparing Parametrically-Driven Topology Optimization with 'Green BIM' approaches

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Abstract

The research presented here reports on current advances in tying simulation and analysis of environmental building performance to design authoring software. A brief review of developments leading up to the convergence between design authoring and environmental performance testing helps to explain the current status-quo. Many of the applications available today are rooted in early research efforts that date back to the early days of Personal Computers (or even before). A small case study complements the historic review and offers some perspectives about tool selection in an educational design-studio setting.

Keywords: Parametric Design; BIM; Environmental Analysis, Design Ontology

Introduction

Analysis and simulation of environmental building performance has been assisted by computational means for over three decades. Convergence between design and analysis tools over the past five years has resulted in various options for architects and engineers to interrogate environmental aspects of their projects. These options unfold on two major pathways:

Firstly, a proliferation of environmental analysis plugins that tie directly into parametric modelling tools (such as McNeel's Grasshopper™), thereby assisting early-stage topology optimization and design exploration. Secondly, the increased availability of environmental analysis tools that interact directly with Building Information Modelling (BIM) software such as Autodesk's Revit™.

In reference to this year's Sigradi conference-theme of Crowdthinking, this paper will compare the two pathways for transdisciplinary collaborators who optimize environmental sustainability of their design via computational means. Advantages and disadvantages related to the process ontology of (free-form) parametrically-oriented modelling and object-oriented (BIM) modelling for testing environmental performance will be discussed.

Methodology

Results presented in this paper draw heavily on literature review in the field of computational design, Environmental Analysis, Building Information Modelling (BIM) and Parametric Design. The author consolidates findings about the development of environmental analysis tools in relation to their proliferation and integration within BIM and Parametric software applications currently in use both in practice as well as academia. A recent design-studio class at the author's home institution further serves as a test-bed to analyze and compare how, and to what extent environmental analysis was tied to either BIM or parametric modelling within the studio setting. The process within the studio focused on bridging the semantic differences between free-form parametric design exploration and object-oriented modelling. Within a thirteen week studio setting, architectural students worked with engineering experts to test environmental and structural qualities of their models both using analysis tools in McNeel's Rhino/Grasshopper™, as well as in Autodesk's Revit™.

Based on examples from the studio the author will discuss the benefits of one pathway for environmental analysis versus another. Most importantly, potential points of transition from using one method to using the other (and vice versa) will be presented. The paper will scrutinize the status quo and the types of environmental analysis possible at this point and hint at gaps to be considered for further research and development.

Background: Using Virtual Models to Test Environmental Building Performance

Research and Development in computer aided architectural design has a long history of using virtual models to test and appraise building performance. Early approaches date back to experiments undertaken by Tom Maver and his colleagues at the University of Strathclyde back in the late 1970s and early 1980s (Maver, 1979,1987) . Over the course of the following 4 decades such early research progressed from using virtual models to test limited sets of environmental factors in isolation to more extensive multi-criteria investigations.

Entering the PC era

The increase in computing power and the development of sophisticated algorithms to calculate and simulate building physics behavior were major influencing factors for the progression of software to test various environmental aspects of building projects. The increasing proliferation of geometry modelling applications in the 80s and 90s furthered the advancement of RnD related to environmental analysis tools both for architecture, as well as urban design (Maver and Petric, 1995). Fostered by feedback from building physics engineering, a number of software applications became available to designers to help them assess environmental factors of their design (Papamichael, LaPorta, and Chauvet, 1997). One of the most prominent applications for building energy simulation was DOE-2 (later advanced into: EnergyPlus™) by the U.S Department of Energy (Birdsall, Buhl, and Ellington, 1990). EnergyPlus™ is continuously being advanced to date and it available as a free download. EnergyPlus™ is a calculus-based application allowing designers to determine 'energy consumption for heating, cooling, ventilation, lighting and plug and process loads and water use in buildings' (EnergyPlus, 2016). Data exchange with EnergyPlus is based on text files and manipulation via spreadsheets. In addition there exist a number of free and licensed graphical user interfaces (The EnergyPlus™ website currently lists the following applications: DesignBuilder, EFEN, AECOsim Energy Simulator, Hevacomp Simulator V8i, COMFEN, Solar Shoe Box, N++, gEnergy, Simergy, Beopt™, Sefaira, Archsim, and EBEST). One common aspect among these user interfaces and software applications interacting with EnergyPlus™ is to help users overcome the need for numeric input of 'knowledge-heavy' and calculus-based engineering data. Without the pre-configured graphic user interfaces and background calculations by some of the applications listed above, many architects would be hard-pressed to conduct analysis effectively due to their limited understanding of the primary benchmarks for testing environmental performance.

Environmental analysis tools for architects

In response to the lack of easily-accessible, as well as multi-objective tools for architects, Andrew March conceived the highly intuitive software application Ecotect™ as part of his PhD research at Curtin University in Western Australia (Roberts and March, 2001). The tool went on to be commercialized by 2002 and was sold to the major CAD software firm Autodesk in 2008. Its key concept was to provide architects and entry-level application to test environmental performance, supported by a library of pre-identified material definitions and rough approximations of building performance based on precedence data. As much as Ecotect™ did not attempt to compete with more sophisticated building physics applications, its easy-access functions and the high speed for calculating outcomes made it highly suitable for trend-analysis by architects and architecture students alike. In parallel to the increasing proliferation of Ecotect™, other software developers such as IES™ started to offer different versions of their standalone applications, ranging from sophisticated and multi-facetted operations, to more limited and easy-access versions. All tools mentioned in this context allowed users to either set up geometric elements within the software itself, or to import topological surface models generated in other software to then add particular material definitions within the analysis tool. By using the latter approach, complex third party geometrical shapes were able to be investigated within the analysis software, often requiring a step to minimize polygon count of its underlying surface geometry.

The rise of the plugin

The early and mid-2000s also saw the emergence of another approach, empowering designers to access environmental analysis operations in the form of plug-ins to topology-based geometry-generation software such as Rhinoceros, Sketchup, and others. The key advantage for designers here was the ability to engage with environmental performance of their designs within the same software environment they used for geometry generation without depending on separate environmental analysis software (and the associated exchange of geometry data).

Attia et.al (2009) compare ten different building performance simulation tools some of which are standalone applications, others are energy simulation plugins to geometry authoring tools. Their key findings reveal the emphasis by designers on graphical representation of output results (to assist their decision-making), the importance of being able to generate comparative reports based on simulation output from different design options, as well as an emphasis on the flexibility of the tool's use and navigation. Attia et.al (2009) further assess differences in the usefulness of bespoke applications during varying design stages; some are more suitable for evaluating conceptual design trends – others are best applied during design development or detailed design. Attia et.al (2009) conclude that key factors of an 'architect-friendly' environmental analysis tool lie within the ease of use based on its graphic user interface (GUI), the ability to compare multiple design alternatives, and the tool's adeptness to handle (and analyze) complex virtual model geometry. In their reflection on architect-friendly tools, Attia et.al (2009) point out the relevance of their comparative study in the light of emerging developments such as the increasing ability to link environmental analysis to object-based modelling in the form of BIM.

Building Information Modeling (BIM) and environmental performance

In recent years, the object-oriented modelling and coordination approach of Building Information Modelling (BIM) has experienced major uptake throughout the construction industry, using virtual models to produce design documentation, take off building quantities, coordinate construction detailing and sequencing, as well as linking construction data to Operation and Maintenance. The first comprehensive summary about 'Green BIM' as then labelled by Kryiel and Nies, has been published in 2008. Research related to 'Green BIM' has since focused on the use of BIM to help architects to check their designs' environmental compliance against local codes, such as the 'Leadership in Energy and Environmental Design' (LEED) certification by the U.S. Green Building Council (Barnes and Castro-Lacouture, 2009), or the Australian equivalent 'Green Star' code (Gandhi and Jupp, 2014). The concept of Green BIM has also been reviewed in the context of economic as well as ecologic factors impacting on building lifecycle analysis (Jalaei and Jrade, 2014)(Akbarnezhad, Ong and Chandra, 2014) (Kwok Wai Wong and Zhou, 2015). Next to the research mentioned above, the use of sustainability tools in conjunction with BIM has been investigated in regard to interoperability between different BIM and analysis software applications (Kumar, 2008), as well as their potential to offer decision-support to designers (Inyim and Rivera, 2015). Azhar and Brown (2009) provide a comparison between the integration of BIM authoring tools Revit™ and ArchiCAD™ with the before-mentioned Ecotect™, IES™ as well as Green Building Studio™ (GBS). The study reveals strong links emerging that tie model data generated via BIM to the analysis functionality of the tools examined.Still, the progression of integration of environmental analysis with BIM functions was not yet sufficiently advanced in 2009 for Azhar and Brown to offer conclusive results. From 2010 Autodesk progressively integrated parts of Ecotect™ into their suite of BIM (or BIM compatible) authoring/massing tools such as Revit™, Vasari™ or FormIT™ in order to augment their modelling capability with basic environmental feedback. According to Autodesk (2016), Revit™ now has the following environmental analysis features built into their core software: Solar Analysis, Sun and Shadow Studies, Daylighting and Lighting, Thermal performance, Whole building energy analysis and Weather data visualization. As a direct result, Ecotect™ has been discontinued as a standalone product in 2015. In 2014, the integration between BIM authoring and environmental performance optimisation has seen a further step forward with the integration of real-time analysis functions of the EnergyPlus™ based Sefaira™ software within Autodesk's Revit™ (Sefaira, 2016).

The increasing relevance of parametric design

In parallel to the increasing proliferation of BIM, parametric design has seen strong uptake among designers in particular for form-finding processes associated to early design exploration. From around 2005 McNeel's Grasshopper™ plugin (initially known as 'Explicit History' to their surface modelling tool Rhinoceros™, facilitated further advantages to users who could now set up rule-based, 'flexible' geometry models to interact with environmental analysis functions (Rutten, 2010). Grasshopper™ offers users the option to apply Genetic Algorithms in for form-finding and optimisation of bespoke building performance (Caldera, Gonzalo and Loyola, 2013). The rule-based nature of parametric geometry definitions lends itself for the fast turnout of design variations in a (numerically) controlled setting. By linking parametrically defined geometry to environmental analysis, users avoid having to re-draw their models for each new geometric setting and parameters stay mapped across geometry and simulation. One major advantage of the way McNeel introduced Grashopper™ to Rhinoceros™ users is the fact that its open-source setup and expandability has led to the availability of a great number free (or low cost) plugins. Similar to the links between BIM and environmental analysis, the Grasshopper™ community embraced opportunities to tie parametric design to optimisation. A plugin (Geco) tying Grasshopper™ to Ecotect™ was released in 2009 and other environmental plugins followed – such as Diva (initially developed by researchers at Harvard University), Ladybug for sun-path analysis, wind-roses (Roudsari and Pak, 2013), or shadow studies, or (the related) Honeybee which links Grasshopper to (daylight) simulation engines such as EnergyPlus, Radiance, or Daysim (food4rhino, 2016).

With the range and diversity of computational approaches to environmental analysis in mind, questions remain about how to best address/test certain environmental issues as part of the design process. What concerns are best tackled during early massing studies? What can best be resolved by investigating the building skin? What should be left to a point in the design when individual material choices and floor-plate configurations are well know? Results from a recent design studio conducted at the home institution of the author shed a light on the above questions.

Testing Performance within a Mixed Parametric/BIM Design Studio

The project developed as part of the studio presented in this paper was a multi-functional event space in an inner-urban setting. Over a thirteen week semester students were tasked to develop experimental morphologies using parametric surface modelling in Rhinoceros and Grasshopper to then translate this geometry to a BIM authoring tool (either Autodesk's Revit™ or Graphisoft's ArchiCAD™). This translation from surface to object-based geometry was facilitated either via Revit's Dynamo™ plugin, or via custom schemers that added BIM-relevant data to geometric entities based on the OpenBIM 'iFC' format. As much as the technique for data transfer does not form part of the investigation presented in this paper, its outcome facilitates an opportunity to compare the use of environmental design tools applied both within Revit™ as well as Grasshopper™. Each student tackled the translation from parametric surface geometry to object based BIM at a different time within their design process. Individual preference and the bespoke selection of environmental criteria to be analysed determined the point of transition as well as the type of analysis conducted to optimize the building's environmental performance.

Results

In reflection on the pathways taken by students it becomes apparent that most opted to engage the Grasshopper plugins Ladybug and Honeybee in early conceptual massing studies in order to test sun and shadow studies, as well as to test reflectivity and glare issues associated to their projects' geometry. Based on this preliminary feedback, students would adjust their project's geometric definition to allow for better penetration of natural daylight, or the articulation of 'slits' and other types of openings within their building skin.

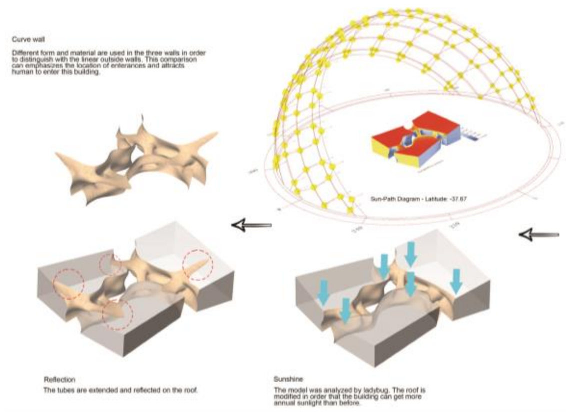
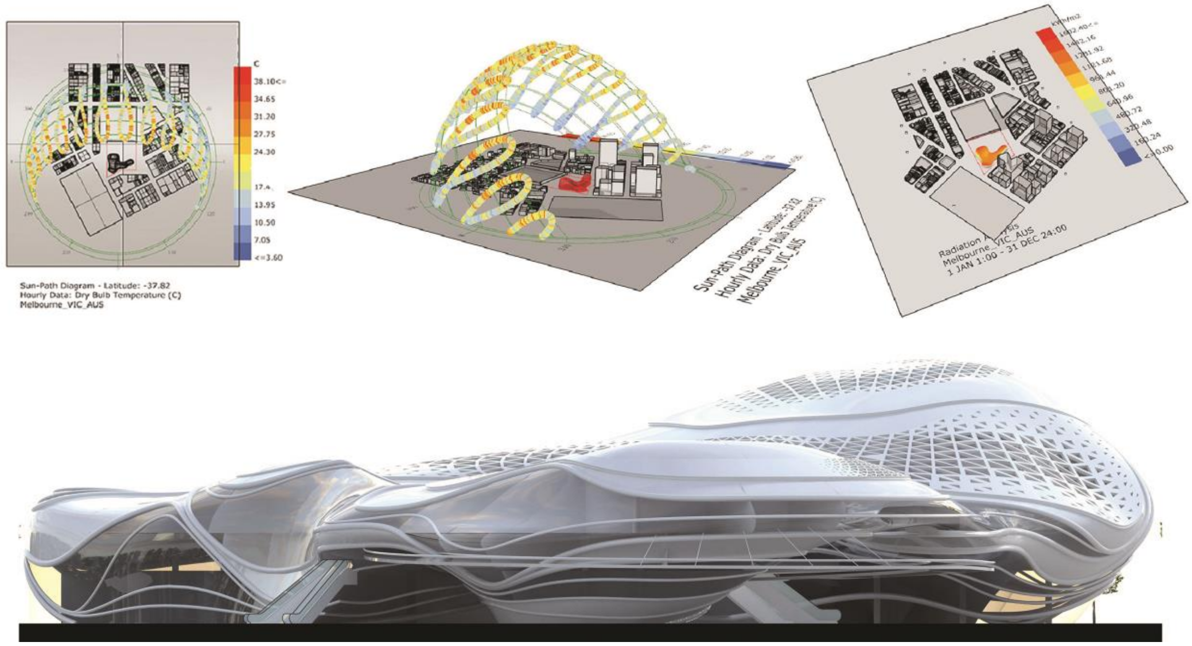


Figure 1: Student work, using parametric design and environmental analysis to adjust daylight penetration of an entertainment venue



Figures 2a+2b: Student work, Sun-path diagram setup in Ladybug™, radiation analysis and final project with parametric surface articulation

Sun-path diagrams were applied to conduct radiation analysis, giving students real-time feedback about the effects of selected orientation, as well as the impact of parametric variations on environmental performance. Due to the fact that all students started morphological investigations of their design in a Rhino/Grasshopper™ environment, they typically opted to remain within their parametrically alterable models in order to test out different volumetric options and variations in the orientation of their proposals. Asked about this choice, students commented that the BIM context would have given them equal feedback, but without the option to carry out major variations of their design in a controlled parametric fashion. As much as BIM tools are also based on parametric geometrical definitions, those mainly typically remain associated to more detailed building/façade components. Students reported that the massing-study functions within Revit allowed for more over-arching parametric changes, but it did not cater for non-standard geometrical shapes to be included. The parametric Revit plugin Dynamo offered an alternative approach to connect more complex geometry to a Revit™ context, but Grasshopper™ was allowed students more flexibility in articulating such geometry in the first place.

Most comprehensive feedback from students could be gained who proactively searched to map out their desired approach to linking environmental analysis to their morphological exploration. Those students first needed to acquire the skill to apply sound judgement about the most appropriate approach to optimization and tool selection according to any given task at hand. Extensive testing of different approaches (partially via the Dynamo/Revit path, partially via Rhinoceros / Grasshopper) was required to build up such judgement over time. In those instances where major morphological changes were required as part of the testing process, Grasshopper™ and the Ladybug/Honeybee plugins remained the tools of choice. In those cases where specific material selection or articulation façade/wall modulations were desired, students would turn to applications that interacted with their BIM models such as Dynamo™/Rhynamo and Sefaira™

Discussion

The pathway comparison highlighted in this paper does not merely juxtapose two separate approaches, but it scrutinizes at which point in their process, students (individually) chose to introduce environmental analysis, and for what purpose. From a design ontology perspective it can be said that students were torn between the production of models of a specific concept or idea, versus models for a particular use. They applied the flexible approach via Grasshopper/Ladybug as a means to produced virtual *models for* rapid decision making followed by immediate design changes. The Revit/Sefaira approach on the other hand resulted in *models of* their design, giving them feedback about e.g. total energy consumption, but with less obvious insights on what parts to change in order to achieve different (optimized) outcomes.

Students had to find trade-offs between an assured pathway based on well-established software solutions (the Autodesk Revit-Dynamo-Sefaira route), or a more flexible and open-ended approach based on open-source plugins (Grasshopper/Ladybug). The former approach offered them a limited set of responses in terms of geometric articulation, but greater certainty of obtaining an outcome. The latter allowed them to remain within the typical morphology development context, but with the associated risk of using as-yet little tested tools with a low-level of sophistication or support. At the time of the studio, direct mapping between the parametrically-based and object-oriented environmental analysis was not possible.

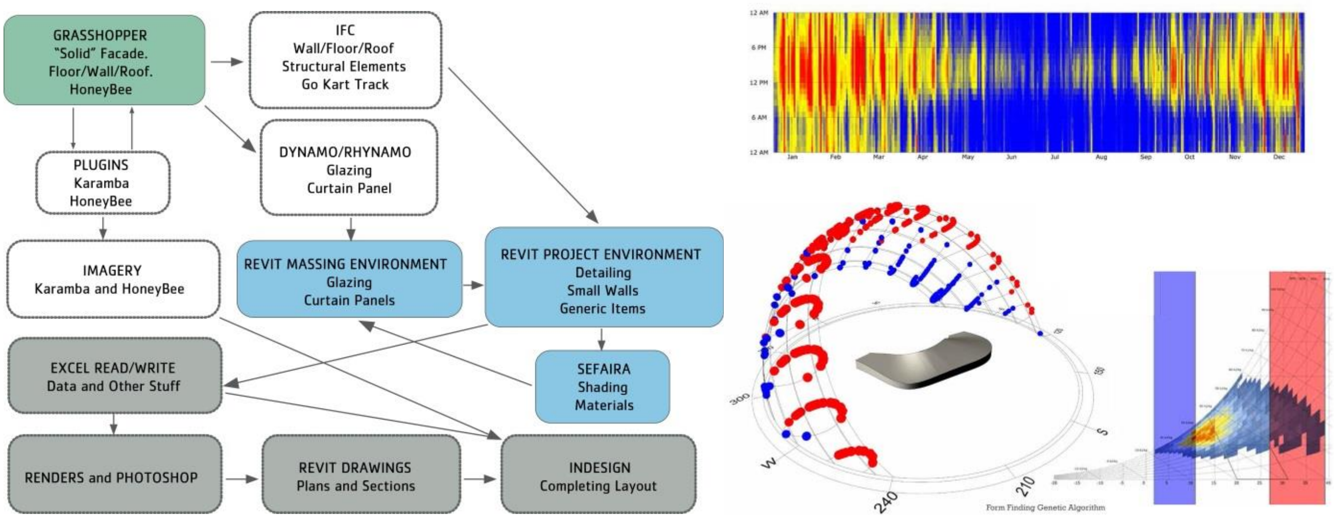


Figure 3: Student work, Mapping out a tool ecology for environmental optimization on various levels of design resolution, associated Ladybug analysis outcome

Conclusions

No matter if environmental simulation is tied to BIM or parametric design, a review of developments over the past five to ten years highlights the high level of 'consolidation' between tools for design modelling and performance testing. Designers are now given an ever greater number of opportunities to interrogate their models and test building performance (against an ever expanding set of criteria) during various project stages. Such tests range from preliminary massing studies, informed by sun-path or shading diagrams, to volumetric studies and area calculations during design development, to more detailed feedback about daylight distribution or human comfort levels based on particular façade-angle calculations. Even further, both (parametric, as well as object-oriented) approaches offer interface between model authoring and performance analysis that assists designers to reduce a project's carbon footprint if a number of environmental factors are taken into consideration.

The validity of results taken from the design studio example is limited due to the small number of participants (16) and the relatively short period of investigation (12-13 weeks). The studio nevertheless offers an opportunity for comparison as all students were tasked to apply parametric as well as BIM modelling techniques in as part of their deliverables. In most cases the nexus between environmental analysis plugins for parametric applications were seen as more intuitive than those for BIM tools. It is suggested here that research in this field will need to be expanded in order to accommodate a larger group of stakeholders and a more extended period of testing.

It will become relevant to test scenarios for cross-linking Grasshopper and Dynamo data in order to allow future users to set up parametric rules that can cut across topology optimization as well as object-oriented design. Such an approach would also help foster the integration of computational fluid dynamic (CFD) capability as seen with Autodesk's Vasari/Flowdesign™ with the increased flexibility in Grasshopper

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