DIGITAL CONVERGENCE IN THE DESIGN STUDIO

Design morphology informed by physical building performance

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Abstract. The increased proliferation of computational tools for building performance evaluation during conceptual design has led to a fundamental transformation in architectural education over the past decade. Morphological exploration and form-finding in the studio setting now gets more and more enriched by environmental performance feedback that allows students to test their design in unprecedented ways. This paper contextualises the underlying developments leading to this changed context that results in greater convergence of information from various software applications, facilitated via digital means. The author presents the process and the outcomes of a recent architectural design studio as an example of how this convergence unfolds in an academic setting. The studio example highlights how the fluid interaction between parametric design techniques and environmental performance feedback enriches the students’ abilities to engage with their design processes in innovative ways.

Keywords. Parametric Design; Environmental Performance Optimisation; Multidisciplinary Design; Convergence; Optioneering.

1. Introduction

The impact of computational tools on creative design exploration across architecture and engineering has been a constant point of research and discussion since such tools have become available to designers more than four decades ago. Various modes of interaction between design morphology and environmental performance feedback were investigated, both in terms of an academic context (Darke, 1978; Ward et al, 1992; Maver, 1997; Iordanova et
al., 2009) as well as their practical applications (Kolarevic and Malkawi, 2005; Chaszar, 2006). These previous efforts either report on custom frameworks that encompass a number of design and performance-analysis capabilities in order to offer operators a bespoke solution, or they highlight the opportunities for connecting existing infrastructures via intelligent data-schemers that allow for an integration of information across otherwise distinct processes or even software platforms.

2. Background

As stated by Mitchell (2009) there exists a constant interplay between tool user and tool maker with one pushing the other for novel solutions. Architects and engineers respond to the various opportunities presented above in a number of ways. Available literature suggests that a well-organised and interoperable tool-ecology has the advantage over the concept of a single platform solution covering design exploration and performance feedback. For that reason, investigations into interoperability across tools and the establishment of tool ecologies have become a primary concern both in practice, as well as in architectural education. Not only do these investigations consider the technical aspect of linking information from different sources, they also consider the resulting changes to the epistemological context and the cognitive abilities of architects and their engineering colleagues.

Parametric Design has become a game-changer in design education and practice (Holzer, 2014). For early-stage design exploration parametric design approaches have proven to be a useful ally to allow designers to optineer design variations connected to building performance feedback. Over the past 10 years, the author has researched this area in great depth in order to investigate the transformation that occurred. The key association suggested here in reference to this period is: ‘convergence’.

Convergence in the field has not only taken place as a cross-over from geometric modelling to performance simulation and analysis tools, but also (and more recently) from early exploratory design towards object-oriented design documentation and delivery tools.

Upon analysis of commonly available software applications in the early 2000s, segregation between geometric modelling and visualisation tools for architects on one hand, and highly targeted engineering tools for simulation and analysis on the other hand becomes apparent. Back then, architects would predominantly focus on formal geometrical explorations and topological manipulations in addition to, or in combination with photo-realistic rendering (Taylor, 2003). The tools available for designers to do so were 3DsMax™, Maya™, Lightwave™, formZ™, or Rhinoceros™, to name just
a few. The increased use of parametric modelling techniques (and referring tools such as Dassault’s CATIA™ or Bentley’s Generative Components™) initially focused on formal geometrical explorations as well. They were only slowly complemented by interfacing tools for building performance simulation and analysis.

The author previously reported on a number of different approaches such as a plugin connecting parametric approaches in CATIA™ with Finite Element Analysis and structural analysis in NASTRAN/FEMAP™ to then link it to a custom developed script for evolutionary structural optimisation ESO (Holzer et.al. 2005). Most of the data linkages presented back then had to be custom developed and they were one-way streets that did not allow for a fluid two-directional exchange of information between parametric geometry optimisation and structural analysis feedback. Based on this research, the author helped to develop a framework (DesignLink) to connect a number of engineering analysis tools to parametric model generation and modulation (Reference withheld for reviewing purposes). In that context, the optioneering approach is discussed in greater depth that complements technological advance in connecting distinct software applications with a novel model of collaboration in a multidisciplinary setting. Both examples highlight the need to overcome the often cumbersome nature of information transfer between design and engineering applications.

The need for establishing closer links between design and analysis did not solemnly stem from designer’s desire to engage more with building performance feedback. Since the mid-2000s, there has been a pull from a number of authorities around the world to include considerations of environmental sustainability in the way buildings are conceived. LEED or BREAM ratings in the US and the UK, and Green Star ratings in Australia (to name just a few). Academic institutions responded to these challenges by adding environmental performance assessment courses to their curricula. Not only has it become relevant for architecture students to understand the impact on environmental sustainability in order to respond to policies and pre-defined targets, they also need to understand how to incorporate environmental aspects into their design thinking within the design studio. Architects can and should not be expected to engage with physical building performance in the way engineers do. They nevertheless benefit from immediate feedback about certain performance trends and they benefit from a better understanding of the underlying principles behind physical building performance in order to engage in more informed conversations with their engineering colleagues.

The author has taught and reported on design classes where the combined use of parametric modelling and environmental analysis was a fundamental element of the programme (Holzer, 2008). These efforts drew on previous
research including work on the environmental assessment tool ECOTECT™ (Roberts and Marsh, 2002). As much as ECOTECT™ offered architecture students an intuitive introduction to a range of environmental analysis functions for evaluating heat-gain, solar and acoustic performance and others, a bi-directional and sustained connection between morphology optimisation and physical building performance was missing. Links from ECOTECT™ to the parametric modelling tools such as Generative Components™ or McNeal’s Grasshopper™ plugin for Rhinoceros™ only occurred one-directionally. Physical (environmental) properties associated to geometric elements needed to be re-mapped to those elements once geometry was altered. Associations between parametrically alterable building components and their environmental performance got lost once parameters were changed.

3. The Period of Convergence

Despite the challenges that lined the path of the integration between parametric modelling and building performance optimisation, the author reports on major progress that has been achieved in this area of investigation over the past decade. In the period from 2005-2015 the use of associative modelling and performance analysis has become mainstream in the architectural design studio. At the same time, architecture students increasingly connect their associative models with an ever growing number of plugins for building performance evaluation. The international SmartGeometry group has been one of the most active proponents of this development, but other groups and events have similarly contributed to the increased uptake of parametric techniques connected to environmental building analysis in practice and academia. In reflection on the progress within this period a number of key developments stand out:

- **The erosion of the boundaries between tools for architectural design and engineering analysis.** There is an ever growing notion of these tools being applied by either group.
- **Greater interoperability between geometric modelling for design morphology and performance simulation/analysis functions with less dependence on export to third party tools for calculations/appropriations of data.**
- **Increased user-friendliness of interfaces that appeal to a more visually driven design approach by architects.** Visual scripting combined with graphic user interfaces and a 3D model environment appeal to architects more than text-based data entry. Better interpretation of analysis results as colour-coded flow-charts, surface renders or plotted graphs. These explicit
display options allow non-specialists to interpret results and understand underlying performance trends more intuitively than mere numeric output.

- **Increased availability and access to tools that perform – in basic terms – the kind of analysis that architects would engage in.** Whereas in the past many analysis functions were deeply embedded in often high-price specialist engineering software, these functions can now be called via free plugins that connect straight to the tool infrastructure available to students.

- **Opportunities to maintain associations across parametric modulation and building performance analysis.** This resulted in a fluid transfer of data related to a design’s morphology and resulting changes to its physical building performance.

- **In general and related to the points made above: an increased understanding by architectural students about the (combined) impact of various design performance feedback on the morphological development of their design.** This results in more conscious decision-making, enhancing a student’s ability to argue convincingly why certain design solutions had been chosen over others.

- **A better understanding about the delineations of what architects should know about building performance in contrast to what information they should query from their engineering counterparts.**

One other major contributing factor to the increased digital convergence in the design studio is the change to the tool-infrastructure available to architecture students. Design students now have access to a plethora of options to connect their parametric models to environmental and other performance optimisation routines that get associated to their three dimensional models. McNeel’s parametric modelling environment for Rhinoceros™ (Grasshopper™) has an ever growing list of plugins and schemers that allow designers to analyse an ever expanding range of issues related to performative aspects of their projects. Upon inspection, one will find close to one hundred different open-source or simply free plugins for Grasshopper™ on the ‘Food 4 Rhino’ support forum/website. These are in addition to an equivalent number of Rhinoceros™ plugins. A great number of these plugins come with online tutorials and associated training/debugging videos.

The level of uptake of a pre-defined tool infrastructure to build up from (such as the Rhinoceros™ Grasshopper context) suggests the existence of a threshold for ‘common’ architecture students in terms of their willingness and/or ability to engage in programming or scripting of new interfaces. Rhinoceros™ has always accommodated options for users to expand on its core capabilities via custom scripts. Still, this option only seems to appeal to a selected few (Burry, 2011). In contrast, the pre-defined plugins for grasshopper
appear to provide a better balance between bespoke entry-level support and the ability for ‘common’ users to expand on those for their custom needs. It is in no way argued here that these predefined scripts provide better solutions for students over those they custom-develop. It is argued though that for a great number of desired applications or ‘effects’ the Grasshopper / Rhinoceros™ plugins offer a platform to pick from, hack into, combine, break and re-assemble in order to suit a student’s needs.

4. Example – The Over & Up Masters Level Design Studio

Effects of the abovementioned digital convergence in the design studio are reported here based on a fourteen week course that was recently run at The University of Melbourne.

The studio explored the relation between morphological experimentation through form-finding, geometry optimisation, and building performance feedback. The author, who ran the studio, was after highly speculative design responses by students, based on in-depth research and inter-disciplinary collaboration between architecture and engineering. Students started the semester by analysing how performance oriented design could inform first principles of conceptual designerly thinking. They scrutinised the role technology plays as part thereof (without focussing on any specific tool).

The author avoided an emphasis on tool and tool use among students at the outset of the semester. Instead, students were encouraged to focus on problem-framing and to consider responses to a number of design challenges associated to the programme (a choice between a mixed-use high-rise tower and an inhabitable bridge). These challenges referred to minimum span distance, the extent of programme to be accommodated, height restrictions and more. The desired learning outcomes challenged students to complement their design activities with building performance feedback, both structural as well as environmental. Figure 1 highlights a student’s form-finding approach by advancing his design thinking with multiple performance criteria in mind.

Figure 1. Darcy Zelenko: Interfaces for structural optimisation via Galapagos and Karamba.
Over the first two to three weeks optimisation techniques and their interface with geometry manipulation were discussed. At that point a number of optimisation tools were introduced to students and their advantages and shortcomings were discussed. Students were encouraged to select a limited number of building performance issues they wanted to address and to research applications that would provide them with decision support in order to investigate them.

In the weeks to follow, students presented their optimisation routines in parallel to the morphological advancement of their design. Two workshops were run throughout the duration of the semester where industry and academic experts provided planning and engineering feedback to assist students in adjusting their design responses. The following observations could be made by the author during the course of the semester: The prioritisation of method over tool was of major relevance at the outset of the semester. Due to the seductiveness of the output of performance analysis, there existed a tangible danger for less critically inclined students to push for performance results without either fully comprehending what they were analysing in the first place, or how to interpret the results provided by the tools they were about to apply. Confirmation bias was another problem to overcome in this context. Some students displayed a tendency to simply use computational means to justify morphological outcomes they had developed prior to running the analysis. Some students struggled with the premise of form-finding over form-making.

The more open-ended process of form-finding by incorporating building performance feedback as shown in Figure 2 was difficult to engage by some, who had to get used to the idea of not knowing what their building should look like at the outset of their design process.

![Figure 2. Farisha Qistina Abd Khalild: Structural topology optimisation using Millipede.](image)

Those students who did embrace the form-finding process still required guidance in order to select those criteria that would most closely correlate to the select number of performance aspect they wanted to address as part of their design. Support provided from an instructor’s perspective mainly related to finding valid trade-offs between seemingly separate performance-
drivers such as solar gain and structural behaviour. In addition, students also needed to develop a critical standpoint about how (literally) to translate from an optimisation response to an architectural project. Students took high risks, engaging in optimisation processes that did not guarantee useable design outcomes at first. In some cases, students custom-scripted plugins to interact with more pre-defined Grasshopper plugins, in other cases students ‘hacked’ these plugins to combine them with other pre-existing tools.

In terms of structural optimisation a great number of students comfortably applied Karamba™ for stress displacement analysis and member size optimisation, as well as Millipede for (evolutionary) structural topology optimisation. For environmental optimisation a number of Rhinoceros™ and Grasshopper™ plugins were applied by students (often in combination). At times students crossed over between using tools such as Geco™, Diva™, Honeybee™ and Ladybug™, depending on what particular aspect of environmental analysis these tools would allow them to investigate in the most direct way, based on the nature of their design. A number of students were interested in testing multi-criteria optimisation via means of Pareto algorithms. The Rhino Octopus™ plugin allowed them to cross-reference structural (wind) behaviour with daylight analysis. In the example shown in Figure 3, Octopus™ allowed a student to map algorithmically optimised design results as thumbnails on a Pareto front for further decision making.

Figure 3. James Holt: Applying Pareto Optimisation to map optimised design options.

All of the tools mentioned above were applied in a highly fluid way, setting up geometric parameters and performance criteria in logical (and interactive) connections that were then analysed from various angles. The one type of analysis where this approach could not be accomplished was the area of Computational Fluid Dynamics (CFD), where the plugin infrastructure associated to Grasshopper/Rhinoceros™ didn’t offer students a useful context to optioneer their design. Instead, students applied Autodesk’s VASA-
RI™ and later Autodesk’s FlowDesign™ (shown in Figure 4) as key pathways to analyse wind pressure on buildings and pedestrian comfort levels related to wind.

Figure 4. Alissa Parveen: CFD analysis for evaluating wind pressures on a tower project.

Throughout the progress of the semester, and in particular during the second half, students became more comfortable with the approach of advancing their design with performance criteria in mind. Once they had decided on their key morphological design drivers they started to get a better grip on the aesthetic intrinsic to their selected approach. At that point it was essential from a supervisory perspective to push them to focus on relating that aesthetic to the functional requirements of the brief such as floorplan layout or key points of circulation. This assisted them to fine-tune their design towards an architectural response that was highly informed by physical constraints. It was crucial that each student was able to explain their design process and that they could clearly articulate and argue for the performance drivers that influenced their design morphology.

5. Conclusions

The Digital convergence in the design studio is an ongoing process. The developments described in this paper point towards the success of highly interoperable applications that plug into existing tool-infrastructure available to students. A key learning process for students during the design studio was to understand when to step back from the solutions offered via the parametric variation and performance optimisation tools in order to make design decisions based on personal preference, style and common architectural sense. Such an approach depended on the level of scrutiny applied by students about the desired level of computational support on their decision making. Further, throughout the semester students increased their sensitivity and understanding related to desired (building performance altering) effects they aimed to achieve and how they needed to engage the code within their Grasshopper™ (or other) plugins in order to accommodate the such an effect.
Most students still relied on their intuition as designers to trade-off multiple criteria that impacted on their design. Only a selected few went as far as to employ computational means to facilitate multi-criteria optimisation using Pareto algorithms embedded in a tool such as Octopus™ or other. Therein lays a field for future investigation. Understanding how multi-criteria analysis and decision support can enrich the architectural design context.

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