Let’s get Physical

Teaching Sustainable Design for Performance-Driven Form Finding

Dominik Holzer
Spatial Information Architecture Lab (Sial) Rmit University, Melbourne Australia
http://www.sial.rmit.edu.au
dominik.holzer@rmit.edu.au

Abstract. This paper presents an approach for familiarizing architecture students with concepts of environmental performance in the early design stages. A design studio was run at the University of Technology Sydney by Leena Thomas and the author where students were applying building performance analysis to inform their design process from the very beginning of the semester. Students were using parametric design and evolutionary structural optimization in conjunction with environmental performance optimization. Michael Hensel and Defne Sunguroglu (Ocean North) joined the studio at half time for a workshop to investigate how processes occurring in nature can be mapped to inform the morphological design process. In spite the multitude of challenges put to the students during the semester in regard to their design methodology and techniques, they were able to produce highly performative and aesthetically pleasing design outcomes.

Keywords: environmental design; structural optimization; parametric design; design education; morphologic design exploration.

Introduction

Teaching environmental design as part of architectural education is part of the academic curriculum of most architecture schools. If it was initially seen as an add-on to the core of architectural design education, it is increasingly becoming recognized as a crucial component in the architectural curriculum.

During the 1990s, government bodies in the western world started to introduce guidelines for environmental and sustainable design of buildings, recognizing the damaging effect of poorly designed buildings on the environment and their contribution to global climate change. These guidelines were developed further to the point where specific targets are now implemented in many developed countries that force developers and designers to conform to a rating system of environmental sustainability. A general shift in thinking is occurring in architectural design to consider not only the functionality and aesthetic of buildings, but also their long-term impact on our environment.

The introduction of CAD tools in architectural education has initially had little effect on the building-physics part as it was mostly used to assist processes that would substitute manual drafting, assist
in form-finding and representation through rendering. Tools for the evaluation of building physics and environmental aspects of design were only accessible to a limited few and they were often based on calculations and on charts in spreadsheets. Only in the early 90s of the past century did we see initiatives for weaving in environmental concerns in the design process through computational means as a major topic in the architectural design curriculum. Back then researchers were calling for tools that would assist them in educating students about environmental issues for influencing their design decisions during their exploratory process and not just tools that would assist them in checking if an already crystallized design would fulfill environmental criteria. (Ward et al. 1992) The problem faced by educators at that point was that the tools available would rather support detailed analysis of the performance of specific building components instead of giving coarse feedback about environmental implications during conceptual and sketch design. Any tool that substantially assists designers in their exploratory process during the early stages would have to complement their established work-flow and interface well with the tools they are using. The research team ABACUS around Tom Maver identified the problem of trading-off accuracy of environmental analysis feedback with availability of tools at the time (Maver, 1997). Whilst accurate feedback is needed, it can only rely on coarse geometrical representation. With the knowledge-based decision support system GOAL ABACUS proposed a method, using relative instead of absolute accuracy.

Hartog et al (1998) suggest that knowledge-based feedback systems for environmental design can be defined as prescriptive ways of integrating analysis with design, but they argue that such systems need to be extended. They propose the addition of descriptive feedback information during the early stage design process to address project specificity. According to Hartog et al (ob.cit.), an ideal framework would be a computational environment that combines knowledge-capture from precedent projects with performance results of the actual project in question to visually compare design alternatives.

A case for a framework as described above that addresses multi-objective design problems has since been made by a plethora of educators and practitioners. Hensel and Menges (2006) raise concerns that tools which allow for sub-optimizing singular functions lead to an architecture which is ‘neufertised’. Instead they ask for spatial organization and environmental modulation through performance optimization with strong references to first principles of energy management as seen in processes occurring in nature. Chaszar et al (2006) state that architects require integrated, cross-discipline and user friendly systems with the ability to visualize complex data and results to support the incorporation of environmental performance data with other types of building analysis in the early design stages.

The issue of representing analysis results coming out of environmental performance is a key element in the quest for tools that allow architecturally trained designers to make sense of results. Architects require visually highly explicit information to assist them in their decision-making processes, ideally directly linked to the building geometry in their models. The creation of such an environment has been pursued in the development of the multi-objective analysis tool ECOTECT® which has become commonly available in architectural education and practice. The tool works on a relational modeling system where roles and relationships of elements to others are derived from the way they are created. As Roberts and Marsh (2001) describe, ECOTECT® allows users to interactively evaluate daylight, acoustics, energy use and costing during the early design stages. Together with their students Roberts and Marsh have studied the uptake of ECOTECT® as design partner in architectural education to apply it on a case study project and compare its usefulness to results derived from physical model-making. The results of their research clearly display the capacity of the tool for providing rule of thumb feedback to students about
environmental characteristics of their design.

With such a tool at hand, how can we push the environmental agenda in architectural education further to explore several design options with immediate performance feedback? In order to address this issue, the author has co-conducted studio based environmental design project together with Leena Thomas at the University of Technology Sydney (UTS) in Australia. The setup of the studio and some of its results are presented in the following chapters.

**Conceptualizing the ‘Environmental Performance’ studio**

The conceptual framework of the ‘Environmental Performance’ studio was based on the goal to confront students with specific tasks for resolving multi-objective criteria of sustainable design in a holistic approach. The idea behind this was to familiarize students with the concept of form-finding as opposed to form-making. According to (Laiserin, 2008) form-making can loosely be associated with a ‘process of inspiration and refinement’ whilst form-finding is associated with a process of ‘discovery and editing where form emerges from analysis’. In this sense students were encouraged to restrain from implementing their usually applied design methodologies in favor of pursuing a design-path that would lead them to unknown territory guided by building performance. The challenge this posed was for each student to apply their judgment on when and how to step in the process as designer and to integrate various performance aspects with their design-philosophy.

Prior to the commencement of the studio all participating students had undergone basic technical training in the analysis of environmental performance and all of them were familiar with the tool ECOTECT®. A further goal of the studio was to challenge the students’ capability of swiftly generating versions of their design and to find ways to instantly communicate their versioning results to environmental analysis. The reasoning behind this was to derive ad hoc feedback of geometrical changes on environmental performance to inform the morphological design process. Parametric design using the tool Generative Components® as well as the ‘Explicit History’ plugin in RHINO® was applied by the students to allow them to create versions of their design templates in a short amount of time.

The agenda of multi-objective performance optimization in the studio was pursued by introducing students to the structural optimization method of evolutionary structural optimization (ESO) next to the analysis of a variety of building physics criteria. The basic principle of ESO is to remove those elements within a (deliberately oversized) structure that are under least stress and allow it to evolve towards highly optimized shape (Holzer at al., 2007). Students were asked to develop their design by applying both environmental as well as structural optimization in parallel. The aim of the studio coordinators was not to see which student would come up with the most ‘optimal’ design but to see how each student would address the complex task differently and complement their personal design capabilities with the performance feedback from their analysis.

To further enrich the studio-agenda a workshop was held at the middle of the semester to test how design-concepts borrowed form nature can serve as a guide for finding over-arching principles for sustainable design. Michael Hensel and Defne Sunguroglu from Ocean North joined the studio for a week-long intensive workshop to explore local flora and fauna from an ecological perspective.

After the intensive workshop students were then focusing on a 6 week design project for a small-scale observation station in the natural reserve. The purpose of the design was to develop and fine-tune its morphology according to its environmental boundary conditions and to address an over-arching sustainability-issue inspired by the previously undertaken exercises.


**Studio description and outcomes**

At the beginning of the semester two small scale environmental design exercises served as starting point for students to explore environmental performance. In the first exercise students were asked to develop a canopy for optimizing shading in the sun-facing backyard of a family-house in association with structural performance. The multi-objective performance criteria included the generation of a structural support system for the canopy using the ESO tool Evolve97 in close connection with the design and optimization of the shading-surfaces. In both cases students were asked to aim for achieving a maximum level of performance-efficiency with minimal material usage while maintaining views out of the building and avoiding obstructions to people-movement under the canopy. In addition to this, students were given the specific performance-requirement that their canopy should shade the sun-facing wall of the building and parts of the backyard to 100% between 2pm and 5pm during summer solstice.

Students were encouraged to work both with physical as well as digital models and to question the outcomes of the performative analysis. By interpreting the results students were then able to advance their design with constant performance checks and to compare the effects of geometrical changes on structural and environmental sustainability in close to real time (figure 1).

The second small-scale exercise challenged the student's capabilities of generating an external screen like feature and wrapping it around the corner of a nondescript 'glass box' office building. Apart from creating a design of interest, students were asked to test the screen's capability to controlling solar gain and allowing for improved daylight distribution in the offices, as well as reducing the solar loads on the façade. In order to quickly evaluate and compare a series of possible options and in order to avoid standard solutions for the pattern of subdivision of the screen, students were encouraged to use parametric techniques for their design.

Students generated simulated views from within and outside of the building to visualize how the screen would get experienced. In most cases students chose GENERATIVE COMPONENTS® for the development of parametric options as well as the 'Explicit History' plug-in in RHINO4® and scripting methods in 3DStudio Max®. The environmental optimization included testing glare and direct solar gain on the working plane, the even distribution of sunlight across the office floor-plate as well as the reduction of incident solar radiation on the façade. ECOTECT® again proved its usefulness for analyzing all of the above. (figure 2)

The mid-semester intensive workshop started off the week with a field trip to a natural reserve located in vicinity of the University to then return to the labs for mapping and the presentation of results. The natural reserve was visited by the studio participants to study the interconnectedness of the apparent high-level diversity of flora and fauna with the prevailing climate, the topography, the vicinity to the sea, the soil conditions and the effects of bush-fires in the natural reserve. A botanist with specific knowledge about the prevailing fauna and flora assisted the students by providing background information about the plants’ lifecycles and over-arching principles for survival of various species. The observations taken into account ranged from the microclimate surrounding individual plants found on a 5 x 5 m plot to the prevailing macro-climate of their habitat. After
choosing a particular plant, students were asked to measure a multitude of environmental conditions (such as temperature, humidity, wind speed, wind direction and daylight intensity) over time to extract quantitative data on its characteristics as well as the qualities of its immediate surrounding.

Once back in the labs of the university, students mapped the results to draw a detailed picture of their plant’s capability to survive and thrive in its natural context. This was done partly by modeling and analyzing the plant’s morphology (or parts of it), and researching the feedback between the organism and its environment. Spatial and temporal mapping was applied to determine topological and geometrical characteristics as well as exploring the processes that would allow the plant to get nutrients out of its environment. In a consequent step, the results were brought into perspective with records of the plant’s immediate surroundings to study the impact the plant itself has on its surroundings (figure 3). For the workshop summary, students presented their mapping process as well as a series of design principles explored during the week to demonstrate their understanding of the implications for architectural design and the scales associated to it.

The final exercise of the ‘Environmental Performance’ was the design of an ecological research station in the previously investigated natural reserve. Students were able to draw upon the context specific research to inform the transference of design principles to the built artefact. Consequently the aim was to continue a hypothetical project for the creation of a small scale research station with an indoor and an outdoor part as vehicle for design synthesis.

The six week long task consisted of the design of an ‘off the grid’ station that would be comfortable to work in with no power available for active heating and cooling systems. Students were to optimize their designs to minimize discomfort due to overheating and overcooling with a goal of remaining in a realm of 18 – 28 deg C for 95% of the year. Further, students were to ensure the enclosed space would have access to glare free natural light for the research activities and to address the two way relationship of the building and its context. In addition to the building performance aspects of the environmental agenda, students explored at least one broader environmental criterion in detail such as water management, material sensitivity (embodied energy, recycling reuse and up-cycling) waste minimisation, or fire resistance (Figure 4).

Discussion

In reflection on the process of teaching an environmental studio with sustainable building performance as driver for design morphology in the early stages following observations were made by the author:

We are currently experiencing a crucial phase in the education of environmental design in the academic context due to the increased availability of tools that allow students to integrate analysis and evaluation of sustainable building performance in
the early stages without interrupting their creative design-process. Critical in this context is the capability of students to seamlessly transfer their computational 3D geometry to those software packages that allow for evaluation of various types of building performance. During the semester the author could observe that some 3D modeling and visualization software-tools such as 3D Studio Max® were sufficient to allow students to respond to basic tasks such as shadow-analysis (as seen in the canopy project) as they allowed for correct positioning and animation of solar angles for specific local contexts. Beyond this exercise, the method of analyzing building performance using the same tool as applied for geometrical modeling was seen as insufficient by most students and they substituted it with a two-step method of using one tool for modeling and a separate tool for performance analysis and evaluation. Using the modeling capabilities of tools like RHINO® and 3D Studio Max® in conjunction with ECOTECT® offered students the benefits of being able to intuitively explore their design with free-form geometries to consequently export their designs to the analysis package for evaluation. It had to be tested by students in how far their often Spline and Nurbs-based geometries would translate into ‘bite-size’ polygonal face-meshes which are required for environmental analysis. In most cases this was facilitated through ‘3ds’ and ‘obj’ export formats. If the number of polygons exceeded a certain limit, it would become impossible to carry out environmental analysis as ECOTECT® would take up to several hours for simple daylight or thermal analysis. In most cases students realized that simplification of their initial geometry in the range of 150-300mm deviations did not result in a major change in the final analysis outcome.

A steep learning-curve enabled students to implement parametric design as part of the ‘screen’ exercise’ within a timeframe for two weeks. Whilst some students were struggling in their choice of parametric design tool (either Generative Components® or Explicit History form RHINO®) others soon discovered parametric principles to be of fundamental assistance in the generation of design variations.
in close to real time. Some students used geometrical representation of the sun-path as base-constraint for the orientation of their screen-patterns. Recent attempts for incorporating aspects of ECOTECT® as part of the Generative Components® (DeBiswas, K.: http://www.smartgeometry2008.com/alumni.asp, May 2008) were considered by the authors but given their early stage of development they were not used as part if this studio.

The week-long workshop at mid-semester offered students to step back from their architecturally-focused approach to environmental sustainability and to open up to ecological life-cycles in nature under specific conditions of the habitats of the nature reserve. At the start students clearly did not operate in their comfort-zone but soon they embraced the method of learning from first principles of energy management as seen in processes occurring in nature to get a better understanding of environmental modulation.

After a strong focus on plant-behavior on a micro to macro scale, some students found it difficult to define appropriate design principles that can be transferred to an architectural scale. During the final exercise for the design synthesis, students nominated ideas of self-shading, water-collection, fire-resistance and wind-modulation as their preferred over-arching principles to investigate. The most difficult challenge during the design of the ecological research-station was for students to let go off the often applied ‘primary generator’ (Darke, 1978) during early design and to avoid latching-on to a simple design-idea to narrow down their design options. Some students started off with a pre-conceived idea about the station’s formal expression and it was difficult for them to then develop their design morphology out of performance requirements. Those students who put a strong initial emphasis on exploring and mapping the imminent environmental and topographical conditions at their site to then relate them to the program appeared to struggle most in the beginning of the exercise, but managed to develop the richest proposals for the morphogenesis of their final project. It was noted by the review panel at the end of the studio, that a high number of participating students had neglected to ‘adjust’ the detailed architectural expression of their station to its apparent performative language by applying standard solutions to elements like openings, furniture and structural detailing. In future courses this would have to be addressed by encouraging students to co-develop these elements in close relation to the overall language that emerges out of the environmental performance-orientated part of the exercise.

Conclusions

With the increasing attention given to environmental performance in architectural practice, academic institutions are confronted with the challenge of sensitizing students to the variety of environmental and sustainable performance requirements that can be found in building-design. In this context it is important to integrate performance analysis and evaluation smoothly in the design process from very early on to become part of the creative thinking as a matter of course. This implies that the barriers for students to apply simple testing of performance criteria and interpretation of results need to be low. In order to facilitate this, tools for concurrent performance evaluation do not only have to be easily available, they also require simple connections to existing computational 3D form-generating software. As described in this paper, we are now at a point where students have access to software that allows them make instant connection between morphological alterations and environmental performative qualities of their design. There is still some progress to be made by computational software developers to allow for an even more streamlined exchange between geometry and analysis data in the early stages. This could either be facilitated by improving the import/export capabilities of such tools like ECOTECT® or similar, or by adding more performance analysis capabilities to computational 3D modelling packages such as Rhino® or 3DMax®.
In both cases it is critical that students understand the overarching principles of sustainable design (as seen in nature) and learn how to interpret analysis results by maintaining a strong hand as designers.

Acknowledgements

Leena Thomas, Michael Hensel, Sunguroglu, and Paul Greenfield

References