Dynamic Façade Design Studio

From sketches to microcontrollers

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The paper presents the outcome of two semesters running a dynamic façade design studio (2014 and 2018) to 3rd and 4th year undergraduates, using computational design, simulation and visualization tools in designing environmentally activated building envelopes. The paper discusses the problems faced by the students and the teaching team throughout the design process and finally suggests ways of integrating microcontrollers as a teaching tool enabling students to comprehend the logic, complexities and overall mechanics of responsive environmental design.

BACKGROUND

Architectural design is ever expanding, morphing and generally exploring new concepts and tools. Motion, transformation, sensing and responsiveness are amongst the topics extensively discussed in relation to architecture over the last few decades mainly at research level and in demonstrative implementations. Such concepts are slowly and carefully threading their way towards postgraduate teaching courses and even less so in undergraduate courses.

Considering the typical design briefs given to undergraduate students and bearing in mind the curriculum of the Department of Architecture at the University of Thessaly in Greece with a strong focus in both representations (digital media, video, gaming, VR) and environmental design (low energy building design), the authors explore a genuine multidisciplinary topic that engages students with a variety of tools and methods. Thus, creating a natural/inclusive environment where all design tools mix transparently, not forcefully and the result simulates a real case study. A process facilitating students' comprehension on the complexity of the design process and where and how each digital tool fits within.

With this in mind, the authors attempt to expand and extend studio design work from a typical architectural design problem solving and form finding exercise, to comprehending the energy design implications, dynamic design solutions, sensing, actuating and general problem solving in both simulation (using Rhino, Grasshopper, Diva or Revit, Dynamo etc) and real scale modelling using Arduino microcontrollers, light and temperature sensors, as well as servos, step motors and/or linear actuators. An experiment in integrating analogue and digital media in an undergraduate design studio.

DESIGN STUDIO FOCUS

The studio explores the design of predominantly south facing dynamic facades on multi storey office buildings in Southern Europe. Among the issues students have to tackle are:

- Design of the office building facade focusing on aesthetics, layering of skin components and the habitable space as would be addressed by the users internal and external views

- Study, understand and simulate the system behaviour under various environmental conditions. Seasonal variations in sun position affecting behaviour of the façade in summer and winter, conflicting needs of lighting, view vs energy gains and techniques that can successfully balance these parameters
- Energy and daylighting calculations using appropriate tools, in order to define and fine-tune the parameters of the dynamic/active components: movement, rotation, morphing, etc.
- Explore and select suitable materials and constructional methods accommodating the above established needs
- Comprehend the whole concept of a feedback loop and optimisation of the proposed solution
- Describe the autonomous function of the system and develop the programming in machine code

Prerequisites are a good operational knowledge of 3D computer aided design and rendering, lighting and energy calculations. Useful to have programming and/or scripting language experience.

LEARNING OUTCOMES

The motive for this design studio is the creation of building envelopes where the barrier to the surrounding environment (the skin) is capable of altering/morphing to accommodate the needs of the users and to adapt to external environmental conditions. Utilising advanced technological solutions creates the need for aesthetic integration of the overall design. Learning outcomes for the students include

- Comprehend environmental control conditions triggering dynamic façade control algorithms
- Design a feasible structural system capable of accepting the proposed mechanism while taking into account various architectural considerations
- Develop simulation models to explore alternative operational modes in an effort to accomplish predefined goals
- Ability to design and implement interactive installations and, in general terms, varying forms of responsive environments

MODEL / PHYSICAL CONSTRUCTION

Unlike the typical semester long design studio projects at our Department where students present their work at 1:50 scale, and scale models are typically 1:100 or more, the students were asked to design all joints, connections, movable elements to a scale 1:2-1:5. Rose joints, bearings, electric linear actuators, motors, forces, cladding element weight, fastening methods, hydraulics, etc had to be dimensioned, drawn and fit in the available space. The projects stressed the physical aspect of the design, thus the need for a scale model of a typical unit.

The research unit of Low Energy Building Design of the Department owns an 4m in diameter artificial sky dome and a 1:5, five-sided scale model cube of a typical room used for real life evaluation of facades. Students had to fabricate a model that fitted the removable external wall panel and visualise the result of their design (through the opposite removable 6th side of the cube) in real life and not only using synthetic images through raytracing simulations.

The reason for building and testing scale models is twofold:

- to explore quantitative and qualitative daylighting issues
- to solve structural problems and comprehend the mechanics of panel displacement and general transformation and subsequently interactions

A few teams managed to scale down the mechanics of the proposed motions, reinvent it using simple servo motors (most initial designs featured linear actuators) and incorporate such motors in their model operated by Arduino microcontrollers. The final stage of this simulation would be to connect

Figure 1
Primrose in Space
[Sourlantzi Eleni,
Stamogiorgou
Martha]

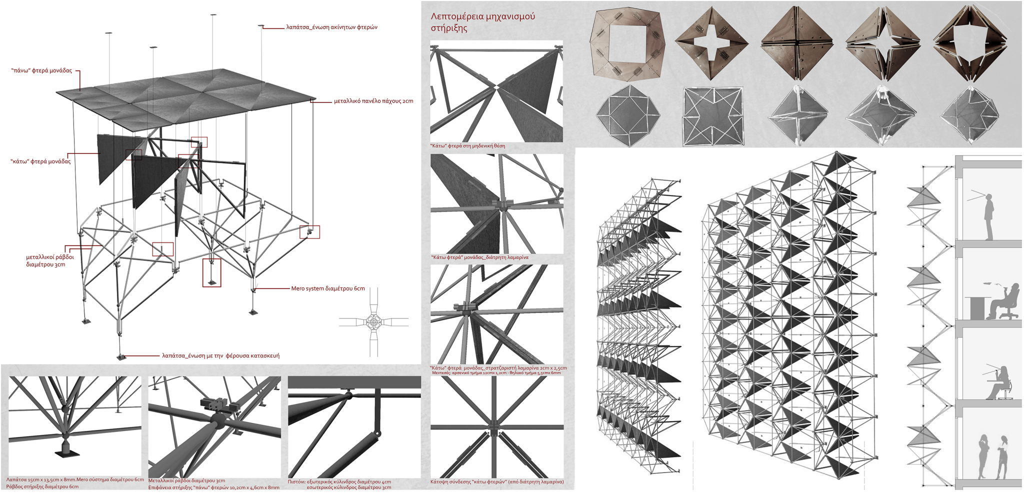

Figure 2
A.Just [Spirou
Theodora,
Stai-Antoniadou
Olga, Tentzeri
Aspasia]

Grasshopper through Firefly to Arduino and simulate movement of dynamic elements using the sun path diagrams as calculated by Diva for the latitude and longitude selected.

DISCUSSION

A great revelation for the students was that maths was all around them and could not be avoided. A couple of students dropped out of the class due to this fact alone. When asked to simulate their initial sketches and early scale paper models, not only in static CAD form but also programmatically describing and animating the full movement of shades, windows, folding or deforming pieces, students had to dig deep into maths textbooks for various geometric definitions and formulas (for example Heron's formula on triangle area calculations from three points) before being capable of putting their ideas in code.

Students do use computers and are competent at modelling. Nevertheless, the topologically complex areas are simplified or only added in the 2D representational drawings. Detailing such areas is often considered outside the scope of studio teaching. However, the same could not be done when the movement and hence the projection of a shading element interferes with solar and light flux entering space. When linked elements fold one next (and relative) to another with pivot points moving along arcs (for the first element) and shade thresholds moving in space along hyperbola paraboloid surfaces or simpler ellipsoids (for the subsequent pieces) the 4D input that the energy/daylighting programs expects becomes a very complex process indeed.

Studio design process was a balancing act between the two disciplines. Students were briefed that they will not design something which will later be simulated for daylighting adequacy and energy performance. Hence, each week both tutors were present at the studio discussing aesthetics, environmental, structural, human comfort, functionality, as well as an expanding range of relating issues. It was beneficial for all, that the two tutors (the authors of this paper) have a long-standing collaboration on scientific research projects as well as art installations and design proposals. It is instrumental to be able to understand the issues at stake and have a continuous discourse on the conflicting areas. To our knowledge this is the first design studio in a Department of Architecture in Greece jointly run by an architect and an environmental design professor.

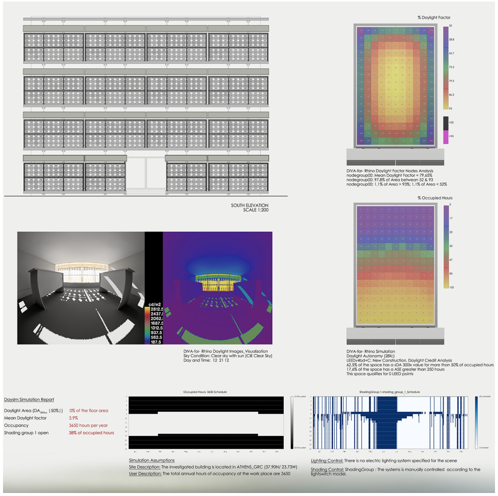

Figure 3
Adaptive Panel
Facade

Figure 4
Structural Mesh
Panel

The mechanics of the whole responsive setup had to be discussed, solutions developed, parts designed, and components (mainly actuators) sized. Weight of moving panels calculated, pivot points established, telescopic properties tested against available actuator products from well-known and widely employed in industrial applications brands (FESTO, LINAK, etc). Non-uniformal extension of actuators facilitating sun following of shading panels lead to non-planar joints, difficult to both comprehend, calculate and design. Industrial solutions, often car front suspension and tracking parts were brought in the studio together with yacht small size hydraulic pumps, rams, stainless steel multicore wire securing and tensioning assemblies. Students became aware of the size and volume of the relevant assemblies and made informed decisions on their placement, whether they are hidden behind other parts or visible, routing for cabling conduits and/or hydraulic pipework etc. Students were concerned that they don't spend enough time designing the building and its facade but discussing and designing its paraphernalia.

Stepping from the physical to the virtual, the well established triptych of sensing, controlling and actuating is elaborated in both media. The theoretical construct of panel movement to satisfy the design idea, develops the mechanics for the panel movement as well as the code that will control the input from the sensors and direct the actuators. The striking similarities to the course on Designing Interactive Virtual Space taught by the first author are stressed and the past experience utilised. Operational scenarios had to be noted down, feasibility tested and approved by both tutors and finally pseudocode was developed and discussed.

Students used Rhino, Grasshopper and Ladybug or Revit with Dynamo to develop the simulation model. Most students were familiar with the parametric design approach and processing of the tools, however they had to restructure their approach as the tools were now used for the animation of the forms defined and not for creation of the forms. Debugging and optimising the simulation, creating the HDR timelapse images and calculating the required energy data/values was also a time consuming process as students had minimal previous experience in such complex integrated setups with dynamically modified shells.

Following was the creation of the final submission scale model of a typical module. A selection of small size (typically 30mm, larger 50mm long) stepper and servo motors together with matching kit of pulleys and shafts/cranks were given to the students to find ways of simulating their established kinetic methodology on the 1:5 scale model. The aim was for the students to introduce actual movement in a typically static scale model. Admittedly certain models fare better than others, namely most light and translucent panels are difficult to model and even more so "hide" a motor in. Solutions where large number of identical or near identical elements transformed in groups could easily hide the motor behind the façade elements and operate through suitable leverage. This step needs more care and thought as often models are structurally incapable in accommodating mechanisms.

The logic and parts of the pseudocode were then transferred with the help of the tutors into the Arduino Integrated Development Environment (IDE), motors and feedback mechanisms connected and tested. Being a completely new field for the students, progress was very slow and therefore next year libraries will be setup by the tutors in advance. Finally, students were introduced to feedback loops and their implementation towards controlling movement - a fundamental notion in kinetics.

CONCLUSIONS

Students who have been successfully through the process of creating animations, writing scenarios, designing interactive digital environments (games, VR applications) and tackling environmental design problems, were able to integrate all this knowledge, comprehend the mechanics of motion, test the behaviour of code in solving real time problems and understand the operation of sensing mechanisms.

Thus, realized the importance of clarity in design to avoid the time-consuming management of complexity in creating successful responsive environments. The authors firmly believe the students are now capable of grasping and tackling real life interactive and responsive scenarios.

A disadvantage of the integrated methodology adopted is the necessity of employing two members of staff throughout the semester for a relatively small number of projects that can be developed within the 2 four-hour sessions a week (typical teaching for design studio in Greece). The relatively small number of students selecting and finally completing the studio is indicative of both the involvement needed and the knowledge that must be attained in advance. However, it is believed that as students better understand the specifics of the course, study the submitted material and mainly discuss with the students that participated, the outcome will be clearer and more attractive.

Authors' plans are to run this course for the at least two more academic years, have more feedback from the students and discuss ways forward and possible similar paths for other design studios. Anonymous evaluation questionnaires for both course and tutors delivered at the end of each semester have a limited appeal to the students (completion rates are very low) hence not enough data to draw conclusions. Authors cannot argue that design teaching is going to be vastly affected by such experiments, the resources needed to pursue such teaching methodologies at a larger scale in design teaching are prohibitive at least for Greek Universities. However, authors firmly believe that kinetics and responsiveness is a discourse that has to be addressed in architectural education.

The nine projects completed during the two semesters as well as the three projects developed but not finally submitted are difficult to describe, analyse and present in text. A selection of submission panels is included in this paper, but readers can visit the course webpage where drawings, description and, most importantly, animations clearly demonstrating the operation of the projects are presented.

http://www.arch.uth.gr/Arch-Design/

FUTURE WORK

During the first year of the course in 2014, the focus was on simulation tools and comprehending the multiplicity of the issues involved. In 2018, the notion of microcontroller augmented kinetic scale models was introduced. Next academic year drawing from the experience already gained, laser cutters and 3D printers will be employed in creating scale components that will facilitate the embedding of the step and servo motors in the 1:5 scale model. The stress will be placed on successfully creating functional kinetic scale models.

This will enable the utilisation of the artificial sky dome with light meters activating the control loop when lighting conditions are altered in the dome. Initially this will be done through a PC running the relevant software creating a two-way link to Arduino microcontrollers featuring both sensors and actuators. Final course aim will be the creation of fully responsive scale models implementing all the necessary functionality in microcontrollers "sensing" the lighting and "controlling" actuators autonomously. This will be the closest to a control system we could achieve in an undergraduate course with the currently available resources.

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