Elemental Intricacy

Architectural Complexity through Hard and Soft Material Agency

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This paper presents the research completed in AA Greece Visiting School 2016 in Thessaloniki. The work integrates computational design and digital fabrication, focusing on aspects of complexity in the making of an architectural interactive prototype. During this research, the use of computation accommodates the design and fabrication of indeterminacy and complexity in different scales and levels. The prototype, Eos, projects on itself the urban characteristics of the city of Thessaloniki. The aim has been to enable a 1-to-1 scale structure to act as a hub of information, capable of communicating with human users through interaction. As the city of Thessaloniki is characterised by specific environmental and urban conditions, the prototype has been set to express such properties.

Keywords: pattern design, 1:1 scale construction, digital fabrication, design simulation, interactive prototyping

INTRODUCTION

The gap of complexity that exists between unsimulatable real world systems and our models of them reflects the fact that the real world often behaves in ways that directly contradict our ideas about it (Frazer 1995, 117). The paper portrays the design and fabrication of a large scale structure through the exploration of human communication coupled with an active built architectural prototype. The case study described in this paper is the outcome of an investigation which has explored low-tech materials with high-tech fabrication tools for the realization of a complex 1:1 scale structure during an international 10-day academic programme in 2016. The programme has run as collaboration between the Architectural Association, School of Architecture and the Aristotelion University of Thessaloniki, bringing together 7 tutors and 24 students from different countries including the UK, Greece, China, Germany and Cyprus. The participants’ background varied in terms of their architectural knowledge, spanning from undergraduate students to professionals in the applied field. The programme’s pedagogical approach was based on team-based design and learning by experimentation, organized through a series of design studios, technical tutorials, and design lectures. The objectives of the research have been two-fold; complex form generation and interaction respectively. Whilst attention is given to the fabrication of the complex architectural form that derives from design variations of a singular geometric element, the prototype’s ability to actively respond to people within its area is also taken into account. It is therefore argued that the final outcome is equally informed by the aim to act as
a human communication node and to be generated through the manipulation of a fundamental geometric element.

The final working prototype is described as a canopy housed indoors, with dimensions of 3 meters width, 3 meters length, and 2 meters height. The design constraints of the prototype have been governed by various factors including material, structural, and interactive aspects. One of the key objectives has been to test the integration of hard and soft material systems in an aggregate configuration. MDF has been implemented as the material for the rigid elements of the structural system, while Lycra has been applied as the soft material as a skin to improve the interactive features of the installation. As the whole piece was devised to work as an aggregate system, the connection details have been a significant constituent in the design and fabrication of the overall system.

PROGRAMME STRUCTURE
The research programme is formulated into two stages; the first stage which runs for 5 days focuses on creating various design models as early trials, while during the second stage, the remaining 5 days, the final 1:1 scale prototype is fabricated. The second stage sees all the participants as one team, combining their knowledge gained from the first stage during which they work as separate teams. Specifically, the first stage has included 6 design teams addressing the research's objectives via the creation of multiple design iterations as a method which enabled the teams to promptly investigate options and filter through the most successful aspects from each design proposal. The purpose hasn’t been to create a single optimal solution, but rather to swiftly test variations that can provide insights via various pattern-testing. The proposals were developed using Autodesk's Maya physics software as well as the parametric plugin Grasshopper for McNeel Rhinoceros. Computational tools as such have been an integral part of this approach emphasising the way in which design and fabrication methodologies that govern the contemporary tendencies of architecture are inherently interconnected with technology. Technology has provided an investigation platform for architects for the analysis and simulation of complexity observed in natural phenomena able to solve architectural problems. The origin of digital experimental methodology in natural phenomena proves that complexity is not an end in itself but the mode and style to solve complex problems of human inhabitation in space using simple and specific rules (Gruber 2011, 110-115).

COMPUTATIONAL SETUP
The design brief of this research has been the proposal and construction of a one-to-one scale prototype with kinetic and interactive parts that relate to the community's liveliness in the city. Innovative interventions which were informed by bottom-up rules extracted from existing city conditions and activities formulated the major focus of the design proposals. These activities focused mainly on the people's movement within the city in different moments in history, the traffic, the city seafront, the connection to the University campus and the weather's local conditions. Simulation tools were used to digitally contort the city's layout and superpose a sequence of flowing particles along the urban grid. Hence, digital tools computed a translation of urban information into organic geometric compositions and fluid trajectories. Furthermore, a diversity of analogue representative models was produced during the form-finding phase of the research. With the completion of this stage, the next step dealt with the realisation of Eos, the final 1:1 scale prototype.

Critical aspect of the research's aim has been the connection between form-finding methods and form-making techniques based on a component-type design strategy. Computational composition and design analysis enabled the architectural solution of a sophisticated shell structure, whose complexity was essential for the agency of space and structural constraints (Terzidis 2006, 117). The prototype's form emerges from a set of design explo-
rations that follow the basic principles of digitally simulated pattern formations. More specifically, a series of forms was investigated through the generation of doubly-curved surfaces that were then subdivided in triangular parts via recursive technique in parallel with aggregation methods of components. In detail, the entire form of Eos is based on a low-poly design piece, which acted as the base model for its' triangular subdivision with Grasshopper. In turn, each triangulated surface produced the set of edge pieces; these were created to act as the structural skeleton for every surface. Each edge was then aligned with its' opposite in a way that every point on that side could be connected with a straight line to the next. (Figure 1) Hence, all components' edges were parallel to each other and vertical to the ground to facilitate this system of connections. The triangulated subdivision continued onto every surface.

Eos has been realised with soft malleable fabric parts for every surface and hard MDF wooden elements for each structural edge (Figure 2). The prototype has been originally installed in the city's University campus where it has been exposed to the people who are visiting or passing through. Whilst constructed in a fixed yet fluid-like form the structure keeps its' active character with the integration of electronics embedded in its' triangular components. The use of the open-source platform Arduino on top of the sophisticated forms designed in Maya and Rhino Grasshopper result in a shell reactive to external stimuli.

The research included the possible integration of parameters and constraints, spanning from the urban and physical environment to the local interior space. The available materials and computer-aided fabrication machines played an equally integral part on the design strategy. Through the digital generation of component-oriented forms, multiple applications of elements were explored in different spatial configurations. Triangular patterns with a gradational change in size respective to pinned-pointed locations over a two-dimensional grid were combined with and fabrication methods through-out the design explorations (Figure 3). These explorations included simulations of cloud particles flowing through the city's fabric and were made possible through the combinatorial use of computational design and mechatronic tools that acted as a common platform (Maya, Grasshopper and Arduino). This digital platform of investigation facilitated the incorporation of a vast array of construction criteria into a seamless complex composition which was synthesised using the triangle as the starting singular geometry. The parametric design strategies facilitated the differentiated application of this triangle to build a complex structural system of polygonal components.
FABRICATION DETAILS

In regards to the fabrication aspect of Eos, the analytical software plug-in Karamba for Grasshopper / Rhino was applied to inform the structure's cells detailed construction which subsequently led to the extraction of data for the computer-aided fabrication (Figure 4). Parametric relationships in reference to user-oriented and material constraints guided the investigation of the prototype's elemental geometry. Under the scope of this methodology the application of specific digital design strategies facilitated the optimization and refinement of the structure and its components. Specifically, the design details of the connection system between the components' edges were generated according to the thickness of the material and the geometric relationships between the neighbouring components (Figure 5). In regards to the analogue and digital feedback, experimentation with physical prototypes informed the digital model. The minimum and maximum magnitudes and dimensions of the polygonal components in the parametric definition of Grasshopper were updated according to the observation of the material's behaviour and the structural components' performance during testing. Furthermore, the geometry of the various polygonal planar parts was modified into double curved surfaces for the application of Lycra fabric. This double curved surface was generated with a digital parametric transformation that was used to highlight the intersections between the polygonal components. The curvilinear geometrical variations of the edges around each void intersection of components created a dramatic effect in contrast to the components edges which had a structural role (Figure 6). Additionally, the articulation of components in distance to each other addressed as a detail the practical issues of Lycra fabric application. The gap between the polygonal components was used to fasten the fabric after the process of assembly and as a design and detail element to highlight the hypostasis of each component. Hence, these design strategies combined structural, constructional, user oriented and contextual parameters in a unified entity under the scope of
a component oriented design.

The parametrically generated structure of Eos required a file to factory continuum for its efficient realisation. The use of parametric software facilitated the digital extraction of components in numbered 2-dimensional spreadsheets for computer aided fabrication in CNC and Laser machines. Engravings on each component edges and connection systems according to the digital numbering were used for managing the complex assembly in the short time frame of the workshop. In this way, students with the help of the tutors were able to coordinate the complex fabrication and construction of the components in pieces and finally complete the assembly of the entire installation throughout a systematic process. Such a complex structure could not be realised without the workflow of data between the digital model and computer aided fabrication techniques.

123 MDF pieces were connected mainly by using a mortise system in combination to fixed steel elements in the prototype’s cellular structure. Initially, the linear MDF pieces were joined into the triangular and rhomboid components which were subsequently connected in the overall network of the shell structure (Figure 7). During this stage, Lycra fabric was applied on the components along with the patterned cardboard elements. Soft, semi-transparent fabric was attached to various cardboard opaque patterns. This configuration was coupled to the kinematics of Arduino servos and sensors. Specifically, Arduino mechatronics were combined with the design of cut patterns on the Lycra to generate complex lighting effects actuated by the distance sensors. As the sensors send signals to Eos Arduino "brain", a set of rotating servo motors, installed and attached on the Lycra skin, begin to move. This moving mechanism has an immediate effect on the soft Lycra skin which at first was designed to have a single layer; however, after testing the overlaying of multiple skins, the double skin was selected as the most effective one to filter the light with a more drastic effect. The moving mechanism of servos behind the fabric transformed the Lycra and generated triangular light refractions in space. The differentiated orientation of components in space and the curvilinear shape of the overall geometry enhanced the organic distribution of light in the surrounding surfaces generating complexity from simple mechanical operations. Moreover, the application of the laser cut pieces on the fabric enabled the transformation to be more specific and directed according to the patterns' orientation. The actual pattern entails greater possibilities of light effects "continuously variable and varying" (Kwinter 2002, 9). In this way, the sensorial attributes of the installation integrate time in relation to geometry of the polygonal patterns and real time data of proximity (Figure 8). Nonlinearity and indeterminacy are manifested through this system of movement in relation to geometry, light and space generating juxtapositions of lighting effects (Kwinter 2002, 9).
Regarding the interactive aspect of Eos, distance sensors were placed to read people's presence within the prototype's area. The sensors were positioned in a strategic part on the structure covering a sensing distance of 450 cm. On the computational part, this distance was divided into 3 different zones; each zone correlating to a different simulation by Eos as well as the triggering of its' kinetic parts. The zone which is the furthest from the prototype acts as the sensing area for the moving mechanism. As the person moves closer, simulated projections of Thessaloniki’s urban fabric are activated on Eos’ Lycra skin. In particular, the city's grid appears initially mapped on Eos single rhombic component. As the distance sensors detect people moving the projected grid gets distorted; city's roads and building blocks are gradually deformed via fluid dynamics. In detail, the system of interaction involves the detection of movement while categorising each movement according to its location. The detection field is distinguished in three areas; each area correlates to a specific fluid simulation that varies in scale according to the distance from the physical shell. Dynamic fluid simulations of particle swarming the city grid and deforming its geometry are displayed while the Lycra fabric is physically distorted by a set of servos connected to it (Figure 8).

RESULTS
Digital and physical modelling facilitated the exploration of part-to-whole relationships between the overall structure and its components. This process contributed in the understanding of complexity in different levels and scales. These different scales include the translation of contextual conditions into projections that influenced the form-finding of the overall structure, the user oriented interactive transformations of the components' fabric with the use of mechatronics, the composition of the shell structure in relation to the components' geometry and the structural and constructional aspects of the connection system. The continuum of design process between large and small scale, digital and physical realm was explored with the use of a digital workflow of data. Laser-cutting and CNC manufacturing techniques enabled a hands-on experience on the diverse range of digital fabrication systems and formulated the starting point for the physical tests prior to realisation of the final form. The physical tests provided a direct feedback for the prototype's final construction methodologies and set the guidelines for the translation of the 3-dimensional form into pla...
A set of design rules was coded in Grasshopper for the digital generation of triangular and rhomboid cell details as well as for the extraction of the 2D spreadsheets used during the fabrication process with the digital machines. In this way, students were able to process the assembly of the geometrically complex structure with the use of digital parametric software.

In regards to the timeline of Eos’ creation and due to the prototypical nature of this architectural project, the different aspects of interaction, simulation, fabrication and analysis were running in parallel. On the aspect of interaction, the different zones in Eos’ sensing and reacting abilities enables an additional level of interplay where a person may at first activate the shell’s moving skin fabric and in turn the shell may attract the person to get closer in steps while different animations are on display.

CONCLUSIONS
At every point of the design, fabrication and the assembly process, the ability to constantly readjust the Eos’s overall form respectively to the alterations of its smallest detail has been a key driver in recognising feeble aspects and putting forward design ideas for refinement. Moreover, the choice of working with low-tech material for a demanding, complex prototype provided useful insights to the unpredictable limitations of a system that aims to act as communication node. The choice of MDF brought forward the hands-on understanding of benefits between adhesive and mechanical anchoring of the pieces. The set of servo-actuators used to twist parts of the flexible fabric skin heightened the prototype’s active character depending on the set’s positioning and the simultaneous designing, fabricating and analysing processes were critical for the design team to swiftly adapt to the complexity of unexpected results. Overall, the purpose of the study has been to illustrate architectural possibilities of altering in real-time the built environment through the use of computational design processes with digital fabrication techniques. Furthermore, the active learning character of the programme’s methodology empowered both participants and tutors to deal with the complexity of conceiving Eos’ design and equally enabled the smooth transition from the digital realm to the materiality of the physical one. In combination with the programme’s limited amount of time, the entire process contributed to the pedagogical aspect of this initiative rendering students more engaged with various design and fabrication methods.

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