Design by Computation

A material driven study

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The paper aims to address methods of creating a system for design through material studies that are employed as feedback on a computational digital model. The case study described in this paper is the output of an exploration that has investigated physical transformation, interaction and wood materiality over the period of two weeks of the international architecture programme AA Athens Visiting School in Greece. Real-time performative form-responsive methods based on bending and stretching have been developed and simulated in an open-source programming environment. The output of the simulation has been informed by the results of material tests that took place in parallel and have served as inputs for the fine-tuning of the simulation. Final conclusions were made possible from these explorations that enabled the fabrication of a prototype using wood veneer at one-to-one scale. From a pedagogical aspect, the research main focus is to improve the quality of architectural education by learning through making. This is made possible using advanced computational techniques and coupling them with material studies towards an integrated system for architectural prototypes within a limited time frame.

Keywords: materiality, computation, 1:1 scale prototyping, simulation, fabrication

INTRODUCTION

‘The organization of a system does not specify the properties of the components...it only specifies the relations which these must generate to constitute the system as a unity’ (Spuybroek, 2004, p.7).

After a long history of fixed architectural thinking and rigid edifices, architects have begun to diverge from the static expressions of their thoughts and realizations. Following the revolution during the 1960s that gave rise to cybernetics, systems and information theory, architects like Chuck Hoberman developed transformable, dynamic systems or architects like Sanford Kwinter formulated the concept of soft systems. Situating itself within the paradigm of a system that is flexible, adaptable and evolving the research investigates methods of realizing computationally generated forms that exhibit attributes of transformation on a one-to-one scale using a singular material system as base.

The research presented in this paper is part of the
output from the architectural explorations of the programme AA Athens Visiting School that took place in Athens, Greece from the 12th till the 22nd of June 2017. It is an educational programme that explores form-finding through digital design and simulation and applies its findings in material systems, creating architectural built prototypes. The participants of this programme, together with their CAD proposals, are encouraged to learn by actively engage in making physical models while maintaining a certain rigor in their investigative ways, in other words getting exposed to analogue computation [Figure 1].

The main objective of the research is therefore, coupling analogue computation within the ever-growing effectuation of digital simulations. While advanced physics calculations have been used in the computational simulations, attention was given in implementing physical experiments in a rigorous manner. One that was documented and acted as a feedback loop; physical materiality became an active informant for both the design and fabrication processes [Figure 2]. As such, it is argued that both physically and digitally exhibited properties are equally critical that provide a reciprocal review during the initial stages of the form-finding.

**METHODOLOGY**

A research methodology has been set in order to address the objectives of the design investigation. The design brief called for a design and construction proposal of a one-to-one scale partitioning system that can exhibit properties of transformation and that is made from wood veneer and flexible fabric. The setup for this proposal was to be realized within a limited time frame. Initially, real-time generative form-finding techniques based on bending and stretching were formulated and simulated in the open-source programming environment Processing [Figure 3]. Key influences in working with bending and stretching forms have been their direct properties correlations to the materiality of wood and fabric in combination with the ability to examine the various digital tests in a respective analogue method with ease.

The various experiments have been influenced by the analogue computation work of Frei Otto. Similarly to Otto’s and his team’s work during 1960-1990 at the Institute of Lightweight Structures, the approach was developed based on material studies. Through the interaction of various elements as well as external stimuli the outputs of these studies were complex and demonstrated variable transformations. Initially, thin paper was used to create scaled models that were still able to depict how material properties
might work in certain conditions and under specific forces. The research continued promptly in testing with wood.

Students focused on using wood veneer as their main building material. In an effort to move beyond its superficial usage as a thin ornament, the studies focused on the structural limits of the veneer. A series of manual bends and twists were made on a set of equally sized veneer pieces. These were applied on basic forms rather than complex formations in order to have a clear understanding of the material reaction to external forces. Spring back and breaking points were documented and a new set of experiments that included the chemical treatment of veneer followed. In that regard, the aim was to empower the wood veneer beyond its natural capabilities and achieve a degree of control on its rigidity versus its flexibility. In detail, options that included coating the wood veneer with water, and with adhesive and with adhesive diluted in water was applied [Figure 4].

These explorations were elemental to the outcome of the research since they demonstrated the way by which the material properties may lead the form-finding process rather than imposing a form on matter. Specifically, different types of materials were used for different purposes. Eventually, partial large-scale models were put together using wood veneer in order to examine the real performative aspects of what the final piece was going to be made of. These large-scale model explorations provided direct feedback for adjusting the parameters of the simulating digital model. Hence providing the ability to fine-tune the simulation and generate a prototype that is both anticipatory in its formation process and participatory in its aim [Figure 5].

In the context of this research, the studies focused on creating a design system that is made out parts and designed through a bottom-up process. Rather than having a global design concept, the process pieces together systems to enable more complex systems to emerge. The focus thus became the interrelationships between the system parts rather than the whole. The studies explored on creating design rules that would specify the interactions between lower-level components. More specifically, wood veneer was cut in lengths of circa 40cmx4cmx2mm. These stripes were tested in terms of their flexibility when bend and twisted while being connected to each other. Different sequences of connection were explored resulting the use of the diamond shape as the most efficient option for the final prototype. Following the brief of the programme, the architectural prototype is to exhibit characteristics of transformability, flexibility while its form is derived from design variables. Hence rules for de-
sign were set; these included the number of connections for each stripe with their neighbor, the ability of the stripe to deform and revert to its initial form, its ability to stand and hold additional weight, and the possibility to expand in a three-dimensional manner. The design rules were conceived in a way that they all influence the final structure on its performance more than its appearance. As such these rules -same as in biological systems where self-organization is observed- rise from local information, without the interference of external directing instructions (Weinstock 2004).

During the simulation processes, various iterations were formulated. These iterations varied based on the degree of bending, the level of softness in stretching surfaces and the adeptness to conform to a high degree of freeform geometries. Initially, static forms were created in the three-dimensional modelling software, McNeel Rhinoceros. The forms’ iso-curves were extracted; they were divided into a specific number of points of specific ID. These were then categorized in export groups and imported into Processing. In Processing, through the use of physics simulation it was possible to recreate the forms and animate those using simulated forces for rotation, tension as well as gravity. The simulation was set by developing specific parameters that controlled the gravity force, the strength of spring effect on the imported curves and their stretching length. The simulation had a dual role; one to give insight on the stability of the structure and the other to demonstrate the limits as well as the possibilities for human-structure interaction. The simulated movements of the model were set to follow scenarios of interaction with a kinetic reaction from the physical prototype [Figure 6, 7]. Thanks to the properties of the wood veneer the structure is light-weight and can also bend in different directions without breaking while attached fabric is adding to the effect of movement. As the physical experiments provided insights to adjust these parameters, the digital experiments that were closer to the desired aim were then exported and imported back into McNeel Rhinoceros for the fabrication stage. In the concluding stages of the construction stage, the sequence of assembly became the driver to workflow for the realization of the final prototype. The lower-level components were pieced together into larger parts and the final structure was created while following a layered sequence for assembly. Being over 2 meters tall and spanning a length of circa 7 meters the prototype was completed in a period of less than 5 days [Figure 8].
RESULTS
The design and construction procedures have shown the high level of interdependence among the analogue and digital expressions in architecture. Whilst the digital computational model operated in real-world constraints, these were executed in an abstract variant. Hence the input from the physical explorations were critical in the proper anticipation of how the end-result may perform [Figure 9]. Anticipation that would not be feasible by mere computer simulations. Due to temperature changing conditions and the connection nature of the components, the structure performed stronger in regards to its structural ability in some parts compared to other parts. The flexibility of its transformational parts was also affected.

The customized interoperability of software was key to the methodology of this research. The structure's form-finding evaluation points have been mainly in terms of its transformation performance and its interactive architectural scenario. The final output as well as the initial design proposals were created using a series of computer programmes, including Processing, Rhinoceros 3D, Grasshopper for Rhino, Arduino and more. Thus, the design did not confine its' process to a single software but exploited strengths of various design platforms all together. While the initial form was created in Rhino, its performance was tested in Processing, following a non-linear setup. Specifically, the forms were distinguished in fixed and non-fixed groups and exported as such from Rhino through Grasshopper. They were then able to be imported into Processing while maintaining their group IDs and being respectively assigned to movement simulation as previously described. In this way, the initial design went through iterations prior to being constructed. Data exchange of the forms also allowed for the prototype to be shared among a large number of team members while maintaining its initial attributes [Figure 9]. Simultaneously, the action-based interactive scenario was being tested physically through the use of Arduino mechatronics devices. Distance sensors were used to detect motion and the information was used to activate movement through rotary servos. The scenario aimed at creating a sensory partitioning system that would twist and turn certain parts when detecting people moving within its' area.
DISCUSSION
Throughout the design and construction stages, this research aims to infuse architectonic space with literal transformation capacities that are driven by external stimuli linked to human participation. By closing the gap between the stable physicality of space and the constant flux of activities existing in it the goal is to improve our relations with and through the built environment.

Besides having potentially positive effects on the human condition, this adaptive construction logic that follows a responsive design process could enable a structure to be reconfigurable throughout its lifecycle hence improving its use by expanding its potential applications.

By making use of the technology that is available today the research responds to the fact that the world is becoming a more interconnected space. A world that with its abundance and its ever-changing nature requires a non-linear approach to designing and building. A world where the architect might shift the attention from the final form towards the development of processes and systems to concepts such as interaction and transmutation, adaptability and participation.

CREDITS
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REFERENCES
Boigon, B 1993, 'Culture Lab1', Princeton Architectural Press, -, p. 221
Spuybroek, L 2004, NOX: Machining Architecture, Thames & Hudson
[1] https://www.youtube.com/watch?v=VesYwG4NBUs