Modular Light Cloud - Design, Programming and Making

Towards the Integration of Creative Actions

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Modular Light Cloud is an installation that is conceived to explore the boundaries of architecture and art. Its interactivity is a metaphor of mutual influences that derive from activities performed in space - associated with motion, sound and light. It is an experimental project focused on the integration of architectural elements, structure, information technology, performing arts, electronics and digital fabrication in architectural education. The project was completed in a two-week student workshop in collaboration with a contemporary dance artist. The students were taught the basics of parametric design, programming of electronic components and digital fabrication during tutorial classes. The making process combined three stages of development: design, construction and programming of interaction. The final form consists of two irregular spatial trusses made of aluminum profiles connected with 3d printed nodes. The profiles are equipped with LED strips and electronic components: light sensors, sound and communication between them. These systems control the intensity of light emitted by the diodes based on the inputs. The result is a working prototype presented as interactive installation featuring contemporary dance artist. It was displayed at art festivals and other events.

Keywords: Parametric design, Interactive installation, Artistic performance, Digital fabrication, Responsive design

INTRODUCTION

Architecture - as discipline - is experiencing dynamic changes in understanding its condition among other creative activities. Contemporary theoretical approach ranges from opinions situating architecture in broader, expanded field (Vidler 2008), seeking inspirations and gaining experience from a wide array of arts and sciences, to positions of architecture as self-referential, independent domain (Schumacher 2011). But even while seeking the roots of autopoiesis of discipline we are encouraged to look outside of it - triggered by experience of interdisciplinarity and cross-referencing, implemented in day-by-day practice. Examination of material, functional, programmatic aspects of architecture, frequently associated with advances in computational technology, must be sup-
implemented by exploration of non-physical, mental, symbolic aspects of our creations. This is the reason why architects tend to cross blurred boundaries between their discipline and fine arts, examining the potential of interactivity, real-time, sensuality, memory, emotions and feelings. Since space is the realm of their creativity, architects experiment with fields of art that use it as one of substrates - like installations. These are not necessarily "architectural objects", or buildings, turned into works of art (like Gordon Matta-Clark works)(Świtek 2013). They are rather dissected aspects of human activity, that may happen in space, like works of Lab[au], Diller+Scofidio, Mark Goulthorpe, Marco Casagrande (Bonnemaison, Eisenbach, 2009). Computational methods facilitate equipping them with sophisticated interactivity, introducing invaluable possibility of adding human factor. Such installations may be perceived as works of art, but also - as created by architects - as specific tools for exploring these peculiar immaterial properties of architecture.

This affinity is not only one-directional. Exploration of spatial aspects of human existence has become a vital theme of discourse related to arts and humanities in the last decades of 20th century, and this interest lasts until now. So called "spatial turn" (Soja 1996) resulted in many works and publications related to these aspects, suddenly there were not only architects who shape our everyday environment. From minimalist roots of "architectural sculpture" leaving white box of the gallery in the sixties of the past century, to architectural scale sculptures of Richard Serra, overscaled objects of Claes Oldenburg, to Olafur Eliasson installations - artists entered the realm of creation in space, treating it simultaneously as substrate and context for their works (Świtek 2013). Moreover, interrelation of contemporary art and problems of the city is getting stronger. "The future of art is urban" as says Nicolas Whybrow (Whybrow 2011).

These mutual influences create inspiring background for experiments related to the potential of space as technically aided field of interaction and expression. On the other hand all mentioned inquires emphasize epistemological role of such experiments in architects' activity. Modular Light Cloud, as described hereafter, is one of the examples.

THE WORKSHOP

Modular Light Cloud (MLC) is an interactive structure designed and built by students of architecture during a two-week summer workshop. The workshop was organized by Architecture for Society of Knowledge master program at the Faculty of Architecture, Warsaw University of Technology. It took place in August 2014. The project was conceived as a result of cooperation between students, tutors and a contemporary performance artist invited to the workshop. The structure, as stated in project's initial conditions, was supposed to be interactive, parametrically designed and constructed using available materials - such as aluminum profiles - using digital fabrication technology.

As part of workshop arrangements the tutors prepared tools and materials for the participants. On one hand, these were hardware equipment elements: LED strips with aluminum profiles, electronic components of various types and a 3d printer. On the other hand, computer-modeling software (Rhinoceros 3d), custom parametric design algorithms (Grasshopper definitions) and microcontroller programs (Arduino scripts) were provided. During the workshop the tutors delivered introductory lectures on parametric design, electronics and digital fabrication. The tutors defined project's requirements and were fully involved in the design process by giving daily desk critiques and sharing their experience in the matter.

The performance artist's task was to act as project's client, define the specifications for the form and interaction as well as to prepare final performance. The role of the artist was crucial due to constant negotiations with workshop's participants leading to improvements in project's solutions. The artist introduced basic knowledge on performance art and provided consultations for students.
Workshop participants gained the necessary knowledge and skills that were later used in design and production process. The installation was shaped taking into account its structural performance, the artist's interactivity conditions, aesthetic values, available resources and time dedicated for construction. After completing the design, the participants took part in the making process that consisted of preparing reactive structural elements made of aluminum profiles and LED strips, assembling electronic circuits with protective elements and connectors, as well as 3d printing of joints for the final assembly that took place during last days of the workshop. [Fig. 1 and 2]

Prototypes and artifacts generated during both design and production contributed to knowledge on the explored technology and were part of iterative process, which led to the final outcome.

MODULAR LIGHT CLOUD

Modular Light Cloud as designed and produced during the workshop is a sum of three complementary components: spatial form, interactive layer and digital fabrication technology. All three aspects affect each other influencing the degree of complexity of the project; hence, they had to be developed in parallel.

The structure is based on two three-dimensional irregular trusses made of aluminum profiles equipped with LED strips connected using 3d-printed joints. The trusses mark an interior space enclosed in a 4x4x2.5 m cuboid. The profiles adjacent to the interior space are equipped with LED strips; whereas the joints that combine them - with electronic circuits. When lit, the LED lamps draw a three-dimensional composition consisting of planar convex polygons. [Fig. 3] The profile lengths were optimized parametrically to match modularity of LED strips. The form's irregularity caused every joint to be unique. Parametric design and digital fabrication provided the designers with a lot of freedom in shaping the structure. However, there were certain limits to be taken into account, e.g. a big number of structural elements combined in one joint and acute angles between them would increase the size and thus production time of such joint. Another condition was the placement of sensors and their accessibility.

One of the principal form-shaping aspects of Modular Light Cloud was its interactive layer. Due to the usage of aluminum profiles equipped with LED strips, two functions could be integrated in one reactive-structural element. On one hand, the profile provides stability and works as a structural member of the truss; on the other hand Arduino-controlled LED lamp complements the structural element with virtual content.

The final part of the project, which physically integrated the above issues, was to develop and manufacture the relevant joint elements. Due to the uniqueness of each joint and freeform fabrication potential, additive manufacturing methods were selected as an instrument of production. In this partic-
ular case a fused deposition modeling based Stratasys Dimension 1200es units were used. Due to the time factor and the limited duration of the workshop, a two-pronged approach to the project was developed. The first goal was to design an abstract model of network structure made of LED fixtures. In this case the objective conditions such as maximum length, stiffness, strength and ergonomics of the project were taken into the account. The second goal was to design aesthetic form of a joint connecting the network elements together.

**INTERACTIVITY OF MLC**

The interaction of Modular Light Cloud is controlled by electronic circuits based on Arduino Nano 3.0 boards. The circuits are powered with 12 V DC and the behavior of sensors and actuators is defined with a program written in C and uploaded to the board using Arduino IDE. The program converts input readings into numerical values and specifies output signals that drive LED strip actions and communication between the circuits. The systems are autonomous and no external computer is needed to define interaction. [Fig. 4 and 5]
The most relevant signal used as interaction input is sound as it is a medium of communication between the artist and the structure. This is due to the significance of noise, vibrations and voice in the performance. Their amplitudes and frequencies affect the intensity of light emitted by particular parts of the structure. Microphones connected to interactive circuits provide readings of sound. Sound wave is a complex signal composed of multiple frequencies of different amplitudes. Decomposition of these frequencies was solved programatically using Fast Fourier Transform, i.e. a mathematical transformation that breaks down complex wave into a sum of simple trigonometric functions, frequencies and amplitudes of which can then be estimated (Cooley and Tukey 1965). This allows custom control of different parts of structure depending on the pitch and volume.

The second input used to affect the performance of the installation is light. Light sensors were built based on a photoresistor and a fixed resistor. Illuminating the photoresistor lowers its resistance and thus amplifies voltage on the fixed resistor. This change of voltage is read by Arduino board. When a programatically specified threshold is reached, the circuit triggers a predefined sequence of LED illumination.

The actuators of the installation are LED strips. Their brightness is controlled using pulse-width modulation (PWM), that is a method of controlling average voltage by switching a transistor, to which the LED strips are connected, on and off at a fast rate (Huang 2011). The brightness can be controlled in two ways. On one hand, the light intensity is proportional to sound input volume. The proportionality is not linear as it is also influenced by the sound pitch. Middle frequencies influence the light to a greater extent than low and high rates. This is because the sounds emitted by the artist are of middle frequencies while low and high frequencies are considered unwanted noises. On the other hand, during the sequence triggered by light input, the LED brightness is modulated gradually from minimal intensity (no light) to maximal and back to minimal after a specified period of time.

The circuits are equipped with a simple communication module used during light-triggered sequences. The communication is binary and takes place through wire connections between every pair of adjacent circuits. By controlling voltage on output pins and reading voltage drops on input pins, a signal can be exchanged between all circuits. The predefined sequence of illumination takes advantage of that possibility. After LED brightness modulation begins in one of the circuits, a delayed signal is being sent to all the adjacent circuits, which triggers LED brightness modulation in those. Then, the signal is being passed to next adjacent circuits and so on. This creates a chain reaction effect that gradually illuminates the whole structure. [Fig. 6]

The structure is powered with three 12V/150W power supplies. Supply wires were placed inside of aluminum profiles the way that groundings of all power supplies and interactive circuits are connected, power transmission wires of different power supplies are not joined, each interactive circuit is powered with exactly one supply and the circuits are connected in parallel to each other. Two signal wires are placed in each aluminum profile that connects two interactive circuits. Each LED strip is divided in two parts, each part being managed by the adjacent circuit. [Fig. 7]
DIGITAL FABRICATION

Between architectural idea and its realization there is an area of discontinuity much wider than the one found in other fields of art (Slyk 2012). By the term of digital fabrication we understand a number of industrial and technological processes aimed at facilitating and speeding up and at the same time eliminating errors in manufacturing products, in the present case architectural elements fabricated via means of additive manufacturing. Of course as with other methods, the choice of a solution entails a number of consequences, such as the nature of the material, manufacturing speed, its resolution/precision. The correct use of a given tool requires a full understanding of its principles and is crucial for the development of valid solutions (Wright 1901). In this particular case this understanding of the machine and freeform fabrication potential of additive manufacturing was used as a complimentary element of research by design approach.

Due to the time constraints the connector element needed to be designed before the final struc-

Figure 5
A node equipped with an electronic circuit.

Figure 7
The artist interacting with the structure.
ture of the Modular Light Cloud. A generative Grasshopper definition was created to address this problem. This allowed for fabrication of prototypes at the stage of determining preliminary scale, function and form of the installation. The network model that was designed later was used as an input to automatically generate all forty-two joints. Although each of the connectors was unique, all of them were generated using the same procedure:

1. The program recognized position and assigned numbers to all nodes in the structure.
2. Additional axis pointing at central part of the

Figure 6
A sequence of LED illumination triggered by a light input.
structure was added, for each of the connectors that had to be equipped with an electronic circuit. Then, for each of the sections beginning or ending at a given point a perpendicular plane was set. On each of these planes, at the intersection with corresponding section a circle with a diameter equal to the diameter of the LED profile plus wall thickness parameter of the sleeve carrying (3 mm) was created.

3. All the circles assigned to that node were moved along corresponding section away from the node's center. The offset was calculated to avoid collisions and overlapping of the forming planes.

4. All circles in that node were capped and connected with minimal surface generating volume of each individual joint.

5. The bushings for LED profiles were generated. These took the shape of tubes.

6. The final step in nodes generation was the addition of spigots connecting tubes with the main element. A number indicating the corresponding node was added on each pin.

7. Finally, the program would generate a list of all the necessary elements needed for the fabrication process.

As expected, the project of joint element had to undergo a series of optimizations at the stage of rapid prototyping as well as during the production cycle of final products. These changes had an impact on two main issues: the time required for fabrication of a single node and thus the whole structure as well as the material usage along with physical properties of the object.

As a result of the design process and discussions, two solutions for the main part of the joint were presented. Although similar in shape, they differed by production time that if multiplied by 42 nodes would sum up for a total of 3360 minutes - roughly 56 hours. Even assuming a continuous use of two printing devices and ignoring the time necessary to prepare the files, post process finished models, etc. this meant more than a day of production. Estimating minimal supply of security it comes up to more than two extra days spent on fabrication. Taking into account already overwhelming production time of over 240 hours as well as other relating matters such as preparing and programing of electronics, a decision was taken to develop the first solution. [Fig. 8]

After deciding on the joint element shape, the next step was to optimize geometry of the tubes that connected nodes with LED strips. The most important issue was the strength of the element, as it had to bear the greatest loads. In subsequent iterations the main parameters such as length or thickness of the walls of the tube elements were changed and tested. No less important was the shape of a hole for mounting electronics and wiring the installation.

However, the internal structure of printed element was the most important aspect of 3D printing technology. In practice only the outer stroke along with a fixed or predetermined thickness were produced as full volume. All of the remaining space was filled with a grid of controlled shape and density. Being aware of this property affected the efficiency of fabrication - both from material durability and economical point of view. In the case of equipment (Stratasys Dimension 1200es) used during the workshops we were dealing with grid deposited in one of three possible variants: Low Density (where the distance between the printed forming lines is about 5 mm); High Density (where the distance between the lines is approximately 2 mm); and a solid (in which following lines are printed one next to another tightly filling...
In this case no grid pattern was created, however it is worth noting that successive layers are printed alternately in the Y and the X-axis. This solution avoids formation of internal stresses resulting from cooling of the material. In the case of the two previous methods, this problem is negligible. This specificity has an impact on a number of interrelated factors that increase with the amount of material used for printing. The first factor is the printing cost, where the relation is direct and closely linked to the budget foreseen for the implementation. The second factor is the printing time, to which the change in the density of the filling is not directly proportional. Incrementing the density by one step increases the print time by 10% to 20%. Which meant that applying High Density grid would take 110% and the Solid one 130% of the basic time needed for Low Density filling. At the same time, the amount of material used will be approximately 140% and 200% in relation to the quantity consumed in Low Density mode. The final factor is the strength of the print. Similarly as in the first point, the relationship here is direct. Applying the High Density grid, which is increasing quantity of a material to a small extent, causes a significant improvement of the mechanical properties of manufactured items.

Based on the experience described above final optimization decision was to fabricate all tubes as solids because of the need to bear the greatest loads and problems with dissectioning of the models exposed to the shear torque. The density of main node elements was based on sketch simulation done in Kangaroo plugin for Grasshopper.

RESULTS AND CONCLUSIONS

The final result is a working prototype presented as interactive installation featuring contemporary dance artist. It was presented in a 10-minute spectacle entitled "Glow". The act is a contemporary metaphorical representation of a music box with a ballerina imprisoned inside. Instead of depending on the mechanism, the ballerina is using it as her instrument. Her actions cause the machine to glow and she is desperate to stay in its light. The performance itself is an attempt to explore relations between dynamic human emotions and programmed, technology driven interactive structure, allowing interpretations related to contemporary, technologized architecture. All the interaction between the artist and the MLC takes place in space, shaped and structured by the installation itself, thus making it again an architectural trope.

Modular Light Cloud was inaugurated during Warsaw art festival Wawa Design in September 2014. The performance was later a part of Syntezje Festival in Cracow and in Warsaw edition of Museums at Night at the Faculty of Architecture, Warsaw University of Technology. The system of structure generation, its fabrication and assembly along with the interactive circuits can be adapted to create different installation versions. It was used as part of 'MONadOLOGia: a Treatise on Relationality’ - a spectacle inspired by Gottfried Leibniz’s monad theory - displayed at Warsaw’s Museum of Modern Art. [Fig. 10]

Technological innovation was not a major objective for the creators of Modular Light Cloud. Interaction, parametric design, digital fabrication and performing arts are not entirely new to architecture and its relation to art, as it was stated in the introduction. However, the collective usage of these aspects in architectural education is noteworthy. During an intensive two-week workshop, students had the opportunity to familiarize with emerging technologies
leading to the creation of an installation based on human-machine interaction. The knowledge and artifacts generated during that time are certainly base for further research and can be developed during future workshops and experimental projects organized by Architecture for Society of Knowledge at Warsaw University of Technology.

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