Transient materialization

Ephemerality, material-oriented digital fabrication

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Abstract. This paper introduces the notion of transient materialization through an exploration of the relationship between digital and material-based digital fabrication. The research was inspired by direct observations of nature’s beauty in the form of thin films. The building block of the experiment is an n-hedron structure composed mainly of soap foam, which is blown into a foam structure. The paper questions this structure’s materiality, examines its physical performance and ephemeral characteristics, and expands on its meaning through an experiment in digital fabrication. Specifically, this experiment demonstrates various configurations of dynamic and programmable foam structures on a large scale of fabrication. The fabrication interacts with the algorithm, which involves a mixture of air and helium (controlled by pneumatic valves), as well as additive chemical substances and thickening agents, all of which exist in a certain space and time.

Keywords: digital fabrication; ephemeral; foam structure; dynamic and transformable; algorithm; chemical substances

1 Introduction

The development of computer-aided designs (CADs) from two-dimensional systems to three-dimensional modelling has enabled architects to digitally simulate and visualise different geometric models in a Cartesian coordinate system. Moreover, with the recent emergence of parametric design modelling, the methodology of generating architectural forms has shifted from the traditional geometric modelling system to associative design modelling [1]. Through the use of this digital and adaptive system, the development of digital fabrication technologies in architecture has been greatly enriched and improved. Data, materials, and construction can be interwoven within this system, which allows architects to control and adjust the process of fabrication.

Digital fabrication technologies, such as CNC milling, 3D printing and robotic fabrication, are rapidly becoming common practice in architecture, and such technologies are currently being explored experimentally to develop prototypes and pavilions. This discussion does not seek to emphasize how these techniques can be applied to the large scale of buildings; rather, its concern is to challenge and
investigate an innovative and novel technology in order to influence design and architectural thinking [2].

This research pursues the notion of transient materialisation to investigate the new design approach of digital fabrication. Transient materialisation proposes immaterial architecture [3] as the impetus for investigating new possibilities and cognition of morphology in architecture through space and time. In addition, the definition of immaterial architecture does not dichotomize architecture as either material or immaterial; rather, it emphasises the invention of an ephemeral dynamic, generated as a result of the capacity of a machine or the properties of materials, information or external environments. Thus, to address the challenge of this novel design in digital fabrication, this process involves experimenting with the physical and chemical properties of materials in combination with digital tools and machines. The potential of the material, combined with environmental conditions, determines the existential path of the shape, from transformation to disappearance. In other words, this paper claims that architecture may no longer focus on durability (i.e., the quality of a building) as defined by Vitruvius in De architecture [4]. Instead, it not only accepts and embraces the concept of ephemerality to represent the tension among perception, contingency, improvisation and immediacy, but also does so within a transient moment that offers a new possibility in architecture and digital fabrication.

This experiment was inspired by the spherical membrane of the soap bubble: a thin film of soapy water that usually has a lifespan of only a few seconds. In losing its spherical geometry, a soap bubble forms a foam based on n-hedron structures joined together. Through an understanding of the properties of soap foam bubbles, the first phase of machine was produced to generate a moving, transient, and ever-changing three-dimensional foam structure controlled by a mixture of detergent, chemical additives, thickening agents, and gas, facilitate by the mechanism and digital information. The dynamic foam structure follows two principles: 1) the shape output is computationally controllable through pneumatics, mechanism, and a pre-defined structure; 2) the real-time transformation and disappearance of its form is determined by the intrinsic properties of the material, the additional substances, and the environment.

This paper first describes the existing works that inspired this experiment. Second, it explains the focal system, including a technical and mechanical overview, the consideration of additive chemical substances and thickening agents, the dynamic and physical experimentation with the foam structure, and the current results of test. The following are the contributions of this project:

- a description of transient materialization, which may trigger the pursuit of new possibilities in digital fabrication;
- the creation of first prototyping machine for programmable foam structures; and
- the development of a framework for developing and testing the materials, mechanisms, foam fabrication processes, and control systems needed to generate a foam structures.
2 Context and Previous Experiments

Several previous works have focused on the notion of transient materialisation. The *Pepsi Pavilion* built by Billy Klüver and E.A.T. in the 1960s; Diller and Scofidio’s *Blur Building* of 2002; *Cloudscapes* by Tetsuo Kondo Architects and Transsolar in 2010; and *Waterfall Swing* by Dash 7, in collaboration with Mike O’Toole, Andrew Ratcliff, Ian Charnas and Andrew Witte, in 2011, all show the influence of immaterial architecture. The *Pepsi Pavilion* (Fig. 1) was perhaps the first collaboration among artists, architects, engineers, and scientists to produce an experience of virtual illusion. The outside of the dome was covered in a water vapor cloud sculpture by Fujiko Nakaya. The system monitors humidity and wind, using nozzles to produce a volume of cloud with a low-hanging effect [5]. The *Blur Building* (Fig. 1) is another instance of a dematerialized architectural achievement combining architecture and technology. In this project, mist nozzles were used to construct a pavilion whose appearance could be changed by the weather. For example, the mist tends to spread out to the surrounding environment if the weather is hot and humid. When the day is less humid, low-hanging smoke appears and follows the direction of the wind. On a cool day, the fog ascends into the sky and evaporates. [6] *Cloudscapes* (Fig. 2) also used fog to create an artificial cloud at a certain height in space, offering different atmospheres through which visitors can travel in the space of a spiral stairway. Finally, *Waterfall Swing* (Fig. 2) developed differently patterned walls of water, which were computer-generated and operated by multiple independently controlled solenoid valves at the top of structure.

Many of the projects described above envisage new possibilities for an architecture utilizing cross-disciplinary collaboration to develop more responsive spaces for living. Inspired by these projects and perspectives, this paper explores transient
materialization to propose that the complexity and perception of architecture may be grounded in the idea of immaterial architecture—an idea that can be explored through the integration of various material potentialities and through examinations of their physical behaviours, of machines, of digital information and of space. In addition, the aim of the project is to take architecture beyond the creation of static forms and into the design of dynamic, transformable and ephemeral material experimental processes.

3 The System

3.1 The Design Process and Technical Choice

The system consists of two main components: a foam-generating machine and a mass supply (Fig. 3). The foam-generating machine comprises a container for filling with liquid, two input openings in the bottom for solenoid valves, a fabric to determine the initial phase of bubble size, a sculpture mechanism, and a shell to support the container and sculpture device. The mass supply includes a helium bottle, an air compressor, a liquid distributor (i.e., a detergent with chemical substances and thickening agents and a pump machine), and control circuits. In this experiment, the control system is composed of an Arduino, solenoid valves, stepper motor driver boards (Big Easy Driver), stepper motors, DC motors, and a water pump. Solenoid valves are used mainly for the adjustment of air and helium, while the sculpture machine with two stepper motors, two DC motors, and two sharpeners are used to adjust the appearance of the foam.

Fig. 3. (1) Foam-generating machine. (2) Mass supply.

Through the integration of two components, the following are generated through the process of the foam structure within this system: In the initial phase, the foam-generating machine is filled with detergent from an external liquid container. The
additional chemical and food substances, which are thicker, as well as the humectant, are added to strengthen the bubbles and decrease the evaporation of soapy water. After the first step, a growing and successive foam structure is produced through the mixture of air and helium, which can be regulated and adjusted by pneumatic control valves. The two solenoid valves are installed in the bottom of machine. The diameter of passage for the pneumatic valves are 1.6 mm, and the maximum work pressures are 4 bars. The values for the parameters of air and helium solenoid valves are determined by predefined shapes. However, due to the sensitivity of the soap bubbles to different environmental conditions, these valves are adapted to reach the same results. Furthermore, the appearance of the foam can also be slightly altered through the sculpture mechanism, which consists of two sharpeners, while the foam grows upward.

3.2 The Substrate: Chemistry Considerations

The foam structure is composed of soap bubbles, which can be rapidly dehydrated and disappear into dry air. Thus, for the sake of preventing the explosion of the bubbles during the generation process and in order to prolong the life span of bubbles, this project experimented with a mixture of chemical substances and thickening agents, including as glycerol ($C_3H_8O_3$), corn starch, and detergents (Fig. 4). Glycerol (also called glycerin) usually is used for skin moisturizing lotions and is highly hydroscopic, which means that it has the ability to attract and hold onto water molecules to prevent the evaporation of water. In addition, corn starch as a ingredient in liquid-based foods, such as soup, and it is able to create a thick and viscous soap that allows for blowing long-lasting bubbles [11].

![Fig. 4. The explosion of bubbles during the generation process.](image)

3.3 The Mechanical Devices

For the purpose of maintaining the contour of the foam structure and preventing redundant bubbles from accumulating on the top of machine, this project developed a mechanism that sculptured the appearance of foam during the process of growth. This device is installed on the top of the machine and consists of stepper motors, DC
Transient materialization - Ephemeral, material-oriented digital fabrication

motors, sharpeners, and a supporting structure (Fig. 5). The stepper motors are used to control the degree of a set of gears, which determine the width of the foam structure. The sharpeners are driven by the DC motors to engrave the foam. According to the properties of soap bubbles, a higher degree of stepper motors may affect the stability of the foam structure and cause a splitting effect while the foam grows upward.

![Fig. 5. (1) Stepper Motors, (2) DC Motors, (3) Sharpeners.](image)

3.4 Dynamics and Physics of Overall Experimentation

This experimental work developed various shapes of foam structures and presented a strategy for increasing the lifespan of foam and balancing its structure in a real-world environment. In addition, through a series of trial-and-error laboratory tests, this experiment found the adjustment of helium and air solenoid valves and an appropriate chemistry to be key points in determining the stability and the average life span of the foam structure. Specifically, two possible methods of generating foam structures—the direction of growth (i.e., a straight and an arc foam structure), controlled by the output of pneumatic valves, and the different pattern of foam structures, determined by sculptural mechanisms—were shown through pilot experiments that took these factors into account (Fig. 6).
The straight foam structure is balanced mostly by the switch controlling the air or the helium solenoid valve during the iteration process (Fig. 7). In this control system, there are four parameters (i.e., the counters for generating helium and air in a specific time period and the output values of helium and air) that need to be adapted automatically throughout the iteration. The switch between the helium valve and the air valve is constrained by the parameter of the counters. Moreover, in order to build a higher structure, after reaching the maximum number of counters, the output values and time periods of helium and air are gradually decreased for each iteration. The chemical additive and thickening agent (i.e., glycerol and corn starch) are added to the detergent to prevent the explosion of the bubbles, which could interfere with the performance of the foam structure.

**Fig. 6.** Left to right: Straight foam structure, arc foam structure, foam structure with a sculpture approach.

**Fig. 7.** The generating process of straight foam structure.
The method of generating the arc foam structure was developed through previous experiments with the straight structure and through a new method that allows for the manipulation of the direction of growth (Fig. 8). The difference between two modes results from an adjustment to the helium and air valves. Within the iteration, the first time period produces only air in the machine, and then switches to the next step, which delivers both helium and air at the same time. The reason the foam structure grows to the left is that the air valve is installed in the bottom left side of machine, with the helium valve on the opposite side. The bubble on the left side, which contain more air, are heavier than the bubbles on the right side. In order to complete the whole shape, the method of producing the straight foam structure is immediately followed by the first phase.

The final approach of sculpturing foam was generated based on the parameters of a straight foam structure and in combination with the movement of the mechanism located on the top of the machine. The appearance of the foam structure was shaped by this device, which consists of stepper motors that manipulate speed and create continuous angles as the foam grows upward (Fig. 9).
3.5 Result

This paper presents two strategies to achieve anti-gravity and programmable foam structures. In this project, the first priorities were the material components and ratio, which served to strengthen the bubbles. As shown in Table 1, glycerol and cornstarch were added to increase life span and prevent explosion of the bubbles. The results showed that the first method of producing foam structures (i.e., straight and arc) can allow them to exist for approximately twelve to fifteen minutes in space. The average life span of foam structures made with the sculpture process is less than ten minutes due to fewer bubbles. Finally, in this experiment, the maximum height of the structure was found to be approximately 1.5 meters (Fig. 10).

Table 1. Ingredients and the examination of explosion and duration of soap foam.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Water (liter)</th>
<th>Dish Detergent (ml)</th>
<th>Glycerol (ml)</th>
<th>Cornstarch (ml)</th>
<th>Explosion (yes/no)</th>
<th>Duration (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>6</td>
<td>500</td>
<td>15</td>
<td>500</td>
<td>no</td>
<td>12-15</td>
</tr>
<tr>
<td>Trial 2</td>
<td>6</td>
<td>500</td>
<td>15</td>
<td></td>
<td>yes</td>
<td>4-5</td>
</tr>
<tr>
<td>Trial 3</td>
<td>6</td>
<td>500</td>
<td></td>
<td></td>
<td>yes</td>
<td>3-4</td>
</tr>
<tr>
<td>Trial 4</td>
<td>1</td>
<td>60</td>
<td></td>
<td></td>
<td>yes</td>
<td>3-4</td>
</tr>
</tbody>
</table>

4 Conclusion and Further Step

The aim of this paper was to introduce transient materialisation as an approach for designing dynamic, transformable, ephemeral and material-based digital fabrication. The purpose of this novel design approach is to argue that an architectural work is not simply a retinal image [12]; instead, architecture coordinates materials that are both embodied and spiritual in essence, ultimately creating a perceptive experience of space. In this project, the foam structure, as an architectural object, is generated by the machine. Due to the intrinsic nature of the material, the structure acts as an organism: moving, transforming, responding and disappearing according to its surroundings, the time and the user. In this way, the floating, uncertain and blurred object of the foam structure induces and enhances the perceptive experience of body in space and time. Through this interaction among object, user and space, architecture may exist between rationality and sensitivity, thus becoming open to an interpretative creation of the conception of space.

This paper contributes to and demonstrates how and why the system to generate foam structures works. However, the current machine is limited to certain strategies. Further research within this project will involve a re-consideration of additional chemical substances designed to increase the lifespan of the bubbles. In addition, different types of foam structures, such as three-dimensional curves, will also be further investigated. Finally, a temporary pavilion will be a further consideration for the application of this project.
Transient materialization - Ephemeral, material-oriented digital fabrication

Fig. 10. A large scale of arc foam structure.

References

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