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, through a mixture of air and helium (used to control the physical properties), 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, in this paper, we demonstrate the first phase of this technology and achieve a programmable foam structure. The experiment presents various configurations of dynamic and transformable 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) and additive chemical and food substances, all of which exist in a certain space and time. 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.

Keywords
Ephemeral material; digital fabrication; foam structure; dynamic and transformable; algorithm; chemical substances and thickening agents

Background
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 large-scale 3D printing, are rapidly becoming common practice in architecture, and such technologies are currently being experimented with for the development of prototypes and pavilions. As a result, a discussion regarding how this technology can be used in architectural practice has arisen. However, though determining how these techniques can be applied to the large scale of buildings is a useful pursuit, the more important challenge may be investigating innovative and novel technology in order to influence design and architectural thinking.

Introduction
This research pursues the notion of transient materialization to investigate the new design approach of digital fabrication. The notion of transient materialisation proposes immaterial architecture as a trigger for investigating a new possibility 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; [2] rather, it emphasises the invention of an ephemeral, dynamic, and adaptive form, 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 material, combined with environmental conditions, determines the existential path of the shape, from its transformation to its disappearance. In other words, the architectural form is no longer considered static; instead, it becomes transformable, its complexity developed by contexts composed of materials’ properties, machines’ capacities, data, and the corresponding space and time.

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 invented 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 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 chemical and food 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 and food substances, the dynamic and physical experimentation with the foam structure, and the current results of test. The following are the contributions of this project:

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

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 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-handing effect. The Blur Building 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. Cloudscapes 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 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 that is flexible, dynamic and transformable, 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 diversity of architecture can 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.

Figure 1. (1) Foam-generating machine (2) Mass supply

System

The Design Process and Technical Choice

The system consists of two main components: a foam-generating machine and a mass supply (Figure 1). 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 and food substances 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.

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.

Figure 2. The explosion of bubbles during the generation process.

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 additives and thickening agent, including as glycerol (C3H8O3), corn starch, and detergents (Figure 2). 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. [3] 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. [4]

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 slightly 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 motors, sharpeners, and a supporting structure (Figure 3). 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.

Figure 3. (1) Stepper Motors, (2) DC Motors, (3) Sharpeners.

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 to be a key point in determining the various growth patterns of the foam structure. Furthermore, we designed an appropriate chemistry to improve the stability and average life span of the bubbles. Specifically, two possible shapes—a straight foam structure and an arc foam structure—were shown as pilot experiments that took these factors into account.

Figure 4. Straight foam structure
The straight foam structure is balanced mostly by the switch controlling the air or the helium solenoid valve during the iteration process (Figure 4). 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 additional chemical and food substances (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.

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 (Figure 5). 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 (per this picture) 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.

Result
This project presents two programmable types of foam structure (Figure 6). From this experiment, it was determined that both structures can exist for approximately fifteen to eighteen minutes in space (Figure 7). Moreover, in this experiment, the maximum height of this structure was found to be approximately 1.5 meters (Figure 8). Finally, the deformation of the curvature, which appears in the second type of arc shape, is due to the vanishing of the bubbles containing helium.

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 [5]; 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. Moreover, 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.

In this paper, the project contributes and demonstrates how and why the system works for generating foam structures, although the current machine only can create two types of shapes. The further research of this project will be the re-consideration of new chemical substances in order to increase the lifespan of bubbles. In addition, the different type of foam structures, such as curve, will also be further investigated in the next step. Finally, after finalizing all steps above, several machines will be developed for generating different foam structures in space.

Figure 8. Arc foam structure

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