GENERATIVE-GLASS: PROTOTYPING GENERATIVE ARCHITECTURAL SYSTEMS WITH ARTISAN’S GLASS-BLOWING AND AUTOMATED DIGITAL FABRICATION TECHNIQUES

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Abstract. This paper aims to investigate the ways in which the traditional processes of glass-blowing techniques could be incorporated with contemporary generative design processes in the realization of new novel architectural systems. Pedagogical issues on how such prototyping processes could be better integrated within architectural education are also discussed. With the use of algorithmic design methodology to generate/visualize the components assembled in multitudes and digital fabrication machineries to produce the necessary moulds/jigs/tools/connection joints, a series of 5 different glass prototypes have been actualized at the scale of 1:1 or otherwise. The work is the direct outcome of a new programme founded and directed by the author as part of the Architectural Association (AA) School of Architecture's Visiting School in 2013. Part 1 briefly introduces the specific agenda and how the corresponding structure of the programme is designed to facilitate the glass research work done concurrently at the digital fabrication laboratory and glass-blowing studio. Part 2 would systematically discuss in detail the design of each of the 5 main glass prototypes made, presented alongside photographs and diagrams to illustrate the prototypes’ respective assembly and fabrication logics. Part 3 would evaluate the work done and project plans for the next iteration of the research in 2014.

Keywords. Glass; Digital Fabrication; Generative Design; Traditional Crafts.

1. Introduction

Despite the increasing use of parametric design software, digital fabrication processes and robotics in contemporary design and prototyping of novel ar-
chitectural systems (esp. with component-based structural/non-structural assemblies), the choice of construction materials used for these aggregation systems generally excluded glass as a potential candidate. More formally speaking, parametrically 3D volumetric blown-glass has not been explored as much as 2.5D slumped or intricately water-jet cut/sandblasted patterned 2D planar glass sheets. Glymph, Shelden, Ceccato, Mussel and Schober (2002) proposed using quadrilateral planar facets to achieve more free-form assemblies, however, the research here undertakes the opposite stance by deliberately working with non-planar glass component in a highly volumetric form using blown glass. Among the most notable contemporary building projects experimenting with non-planar glass, includes the Prada Aoyama Epicentre (Tokyo) by Herzog & de Meuron in 2004, the Hungerburg funicular railway stations (Innsbruck) by Zaha hadid Architects in 2011 and the Vakko Fashion Center (Istanbul) by REX in 2011. All three projects have used digitally standardized/customized-fabricated moulds and the natural slumping of flat glass panels to achieve a more 3-dimensional form in glass. McGee, Newell, Willette (2012) has similarly experimented with reconfigurable jigs/moulds to explore the potential of slumped glass in a more economical and academic manner. Even projects that have employed blown-glass in smaller scale or as art installations, such as R&Sie(n)’s “Isobiot®ope (thebuildingwhichneverdies)” in 2010 and “I’m lost in Paris” in 2009, have remained as autonomously arranged/supported glass artifacts with no specific structural or geometric aggregational concerns among glass components. Thus, this research attempts to create a means for architects and students to explore blown glass in their aggregated formation using both traditional and contemporary mode of fabrication. Such a task requires a rethinking of pedagogical approach, as well as, a consideration of a number of obvious associated logistical factors. Firstly, expensive glass-blowing facilities do not usually exist in architectural schools or research laboratories. Within the UK alone, only the Royal College of Art in London and the Edinburgh College of Art offer both M.A. in Glass and Masters in Architecture (i.e. RIBA Part II). However, it is not their Department of Architecture, but the Department of Ceramic & Glass, which is equipped with the glass-blowing facilities. Deliberate inter-departmental collaboration and research has to be forged in order to facilitate any productive form of access and experimentation. Not surprisingly, glass-blowing as a design/production process is typically being categorized under traditional small/medium-scale crafts only available within such art colleges. On the other hand, architecture schools with the most advanced in-house digital and robotic fabrication facilities in the UK, do not have such ease of access to any sort of glass-blowing facilities or expertise. Secondly, the diminishing availability of
skilled glass technician and the highly specific glass material specification used in glass-blowing makes prototyping with glass even more difficult, regardless of any well-equipped digital fabrication laboratory one might possess. In view of such economical, logistical and pedagogical issues involved in order to achieve the research agenda with blown glass, the research program has been reformulated iteratively and finally taking the form of an 11-days AA Visiting School (ref. Figure 1) held simultaneously at Tamkang University’s digital fabrication laboratory and Tittot Glass Art Museum’s glass-blowing (hot & cold) workspace in Taipei. An unusual mix of expertise ranging from glass artists, engineers, architects to computational designers are gathered to form the core teaching team. Here, in the form of a feedback loop design process, digital computation is constantly informed by the actual glass’s material computation observed. The unique collaborative exchange processes involved contrasting pedagogical approaches which are adapted to undertake the teaching of both code-based digital workflow and glass-blowing manual craft workflow to students simultaneously within such a restricted time-schedule and available resources of the programme. The following sections will discuss the 5 prototypes made during the course in greater details.

2. Prototypes

2.1. PROTOTYPE 0: GLASS-MOULDED

This is the first series of glass (ref. Figure 2) being blown into a set of digitally fabricated mould made in plywood prior to the subsequent prototypical research on aggregating them collectively. The intention here is to have a hands-on exercise with glass-making itself and see how these experiences would further aid the students in designing more realistic prototypes during the later part of the programme where aggregation logic is to be embedded.
Each student was asked to experiment with any form with the only constraint being the intuitive anticipation of the behaviour of glass when blown into the mold and a specified block dimension. The digital models were modeled in Rhinoceros and each layer was automatically generated from a custom script definition in Grasshopper (a Rhinoceros Plug-in for visual scripting). Air vents were also strategically placed in the digital model as a means to regulate the air pressure of the glass during the actual blowing process. Due to the method of fabricating the moulds, all the glass prototypes are characterized by a number of similar qualities. Firstly is the natural ‘contoured’ surface produced—which is a direct result of layers of laser-cut plywood being stacked together to describe the ‘positive’ digital geometry (ref. Figure 3). Secondly, occasional bumps are seen being imprinted where the air-vents are positioned, creating interruptions to the continuous ‘contoured’ surface. Thirdly is the loss of formal and textural resolutions with subsequent production due to the gradual deterioration (i.e. burning) of the original mould when the hot glass bubble come into contact with it. Fourthly is the typical ‘chamfered’ overall profile of the geometry necessitated by the need to being able to blow into and remove the glass bubble via the single top opening of the mould. Lastly is the size of the prototypes that is directly constrained by the maximum size of the kiln opening (i.e. glory hole). However, a few of the designs did managed to overcome the last 2 constraints by splitting the mould into 2-4 vertical sections, despite the difficulty of keeping these sections together during the actual glass blowing process.
A number of other precautionary setups are made to all these moulds. This include keeping the moulds damp, in order to release a layer of water vapour to avoid the hot glass surface from being stuck to the plywood mould; using clamps and additional jigs to ensure a full immersion of the hot glass bubble into the mould; hand-held fire extinguisher to prevent further burning of the wooden mould when it catches fire due to prolonged contact with the hot glass bubble. Furthermore, there is another series of annealing and cold working to be done after the hot blowing processes mentioned. These include varying degrees of sawing/sandblasting and polishing.

2.2. PROTOTYPE 1: GLASS-MATRIX

Glass-Matrix (ref. Figure 4) is a simple reinterpretation of the standard architectural glass blocks commonly used today and even dates back to the 1900s. Here, each of the 3 different modules is able to interlock with its neighbours when laid 3-dimensionally according to a generative sequence facilitate by a custom-written Processing/Java interface (ref. Figure 5).
Unlike standard glass blocks, whereby 2 hollow halves are annealed to form a partial vacuum in the middle, Glass-Matrix has no vacuum and its various parts are produced using 3 different moulds with single niche. The 3 basic modules are made up of the 3 parts in various configurations (harnessed with UV glue) and textures. The 3 textures included clear, sandblasted and patterned surfaces (i.e. using laser-engraved plywood inserts). The intention is to create a larger 3D volumetric assembly with differentiated transparency, patterns and porosity.
2.3. PROTOTYPE 2: GLASS-NETWORKED

Prototype 2 consists of a simple cone-shaped geometry as the most basic unit. The process that led to the proposed aggregation logic evolved from a succession of glass-blowing exercises, mould-making improvements and 3D printed joint adjustments. By taking advantage of the structurally strength afforded by conic geometries, the final prototype (ref. Figure 6) is a hybrid system of steel, ABS plastics and glass, with joints attached at the apex of each conic unit and branching off recursively. The structure itself is generative – with the ability to grow and change, relying on redundancy, complexity, connections and irregularity, whilst at the same time naturally creating a coherent whole collectively. A custom interface written in Processing/Java is used to generate these various configurations with a fixed set of 4 different ABS joints types and a variable set of steel rod’s angle/length (ref. Figure 7).

Figure 6. Glass-Networked: ‘Self-structural’ glass conic sections

Figure 7. Glass-Networked: Diagram illustrating the parameters and growth logics embedded within the system.
2.4. PROTOTYPE 3: GLASS-BRANCHING

The concept of Prototype 3 (ref. Figure 8) is derived from the branching logic of Lindenmayer system (L-system) as a means to digitally compute the generative aggregation of the proposed glass component. An iterative design and glassblowing process, informed with trial and error, further led to the development of the final 2-Type Branching modules. Custom script is subsequently written in Processing/Java to visualize and varies the branching rules and parameters of the system according to the constraints set by the proposed modules. The intention is to create different collective configurations and then assemble them as possible architectural entities (e.g. ceiling, columns, walls...etc). Unlike the other prototypes, here the hot glass is first pulled into thick glass tubes and then laid on the prefabricated planar 'stencil-like' plywood moulds in order to control their final curvature. 3D printed ABS cylinders are made to then connect one module to the other in a vertical stacking fashion, not too dissimilar to an inverted ‘L-System Tree’ (ref. Figure 9).

*Figure 8. Glass-Branching: ‘Branching’ pulled glass tubes*

*Figure 9. Glass-Branching: Diagram illustrating the basic modules’ logics and their respective moulds*
2.5. PROTOTYPE 4: GLASS-EXTRUDED

Prototype 4 (ref. Figure 10) is based on the concept of pulling hot molten glass as a means to find glass’s own natural form and structure under gravity/applied forces. Instead of an enclosing mould with glass being blown into, the mould consists of only a flat plywood base with steel nails distributed in a digitally composed pattern. Originally inspired by the attractive and repulsive forces of a magnetic field, here the steel nails act as ‘attractors’ when they come into contact with the hot glass surface, thus ‘pulling/extruding’ the glass during the process. In fact, it is necessary to heat up the nails beforehand to ensure ease of detaching them from the cooling glass. Among the various parameters that governs the final glass formation is both the rate of pulling and twisting of the hot iron holding the hot glass bubble at the other end and the amount of glass used (i.e. size/thickness of the hot glass bubble). For instance, the faster the pulling, the longer the glass strands produced, but also the higher the risk of breaking the strands along the way. Grasshopper (Rhino-Plugin) was originally used to quickly create engraved positions for the nails to be placed on the plywood base-plate according to a parametric pattern that automatically align multiple modules in a predefined way. However, there is no way to predict how the final glass would look like since other critical time-based parameters such as glass temperature, rate of pulling and twisting are not encoded. In order to rectify these issues, a custom-software is currently under-development by the author, whereby users could easily create patterns parametrically to layout the nails via a robotic arm and visualize the generated digital and physical geometries in real-time (ref. Figure 11).

Figure 10. & 11. Glass-Extruded: Photograph of a sample taken from the Prototype 4 series (Left) and Custom-software developed by the author for the Prototype 4 series (Right).
3: Conclusion

The pedagogical approach taken has indeed allowed participants to have a very hands-on experience of glass, in relation to the process/tools of digital fabrication. Unlike the pedagogical and formal experiment done with slumped glass to create a glass chair by Duarte, Heitor and Mitchell (2002), where students could only understand the behavior of glass through an iterative process of remote design dialogues with the overseas glass manufacturer and eventually having only the possibility to produce a single prototype, the “Generative-Glass” research has successfully overcome such limitation and allowed a more direct way of working with glass. The 5 glass-blown prototypes discussed here have managed to explore highly volumetric component-based design without the use of any flat glass panel or any overarching structural supports. All the prototypes are designed and made to quicken the process of blown-glass experimentation, without the typically extensive time and cost involved. Students have also benefited greatly having being able to interrogate the behavior of warm glass with a simple yet intuitive play of physical procedures and then speculating these in larger architectural context through subsequent renderings. Apart from these, perhaps one of the main failures is the partial automation of the entire workflow (esp. cold working of individual prototype and the physical assembling of the collective prototypes). Thus, the next iteration of the research, called ‘RoboGlass’, aims to address these issues with the introduction of robotic arms within the glass-blowing studio to automate some of the highly time-based processes.

References


