Augmented Fauna and *Glass Mutations*: A Dialogue Between Material and Technique in Glassblowing and 3D Printing

Best Paper Award

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ABSTRACT

3D printing allows unprecedented freedom in the design and manufacturing of even the most geometric complex forms—seemingly through a simple click of a button. In comparison, the making of glass is an analogue craftsmanship, coordinating an intricate interplay of individual tools and personal skills, giving shape to a material during the short time of its temperature-based plasticity. The two artworks discussed in this article, *Augmented Fauna* and *Glass Mutations*, were created during the artist's residence at the Pilchuck Glass School and articulate a synthesis between digital workflows and traditional craft processes to establish a digital craftsmanship.

Prologue

In December 2016, I was invited by the Creative Director of the Pilchuk Glass School, Tina Aufiero, to participate as Artist in Residence in the summer of 2017. I was intrigued by the theme for the residence, "Taxonomy," and decided to create a family of objects situated between my digital practice and the traditional glassmaking process to articulate a potential synergetic quality between the two.

In order to explore this relationship I planned two lines of inquiry into glassblowing and glass casting. Additionally, I set up a dialogue between the materials and processes used in the resulting objects and examined the advantages and restrictions occurring in the translation between digital and traditional methods. Therefore, the artworks would retain qualities of the different toolpaths and workflows. The traces of each process would allow me to identify synergies and new narratives between them.

Conceptual Framework

Traditionally, craftsmanship is understood as the interplay between tool, material and the skills of the craftsman. By contrast, digital design environments are not operating in the realm of physical materiality and its tooling. Instead, they poorly imitate the hand and eye coordination of the craftsman through interfaces such as the computer mouse and screen. This dichotomy is based on the notion that craftsmanship is solely understood as skilled manual labor. In Richard Sennett's seminal work, *The Craftsman* [1], he extends this notion and articulates craft as a human impulse to do a job well for its own sake—including computer programming. My discourse on digital craftsmanship, based on Sennett's writing and through the concept of the digital hand [2], is one that embodies craft as a cultural and sociological construct.

In order to establish this construct as a relation between digital practice and traditional craftsmanship processes, the project revisits the conceptual pair of techne and poiesis posited by Martin Heidegger. I argue specifically that Computer Aided Design (CAD) can be read as techne which, for Heidegger, does not describe *Technik* (technology) but constitutes the "bringing-forth of the true into the beautiful" [3] and thus extends the basic definition of "how to" to the actual genetics of the making itself. Reciprocal to techne, poiesis is the activity in which a person brings something into being that did not exist before. It articulates the making of the works and the intent behind the processes and their reevaluation in the context of craft and or digital workflow [4]. I further articulate this reading by comparing it to phase matter states, in which Sublimation and Reification act as techne and the methods of Amalgamation/Augmentation as poiesis.

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Techne:

The term Sublimation describes the transition of a substance from solid to gas phase without passing through an intermediate liquid phase. This process of dematerialization is comparable to the digitization of a physical object—a solid melting into digital air. It is the interface between an actual object and the digital 3D model becoming prosthesis, a doppelganger or "cybrid" as described by Peter Anders [5]. Thus, the emergence of a malleable information space enables intervention into the otherwise static properties of physical objects [6]. Sublimation is able to establish the transfer of traditional craftsmanship into digital workflows.

The results established a dialogue between immaterial and material processes and emerging properties based on craft and digital workflows and became the basis to articulate my notion of Digital Craftsmanship.

Poiesis:

Augmentation describes the addition of a prosthetic element into an existing form. I worked with the biological remains of a pelvis bone from a Pilchuck deer. The conversation takes place between a found object, its glass prosthesis and a negotiating sublimating 3D scan—and ultimately, printed—digital doppelganger. For this I chose what seemed comparable to 3D printing—glass casting.

Amalgamation is the combination of two or more components into a construct, where the initial components cannot be separated or read individually after their merging. Components therefore exist only in synthesis and form a new object that adds up to more than the sum of its parts. In this second argument, the finite sublimated form of the cast as a simulacrum of the physical original is replaced. Instead, the second work series uses glass blowing in synchronization with digital workflows of scanning and printing.

Fig. 1. Panorama view of the setup of the Artist in Residence studio at the Pilchuck Glass School including 3D scanning and printing station. (© 2017 Tobias Klein)

After three weeks of experiments, revisions and successes, I filled a room with glass casts, scans, drawings, 3D prints and glass blow specimens (Fig. 1). The results established a dialogue between immaterial and material processes and emerging properties based on craft and digital workflows and became the basis to articulate my notion of Digital Craftsmanship. Extending Neri Oxman's definition of digital craftsmanship (the ability to simulate and compute material behavior and design) [7] and the digitally derived formal exuberance [8] of Dillenburger and Hansmeyer's Subdivided Column [9] and Digital Grotesque [10], my work is situated among those by artists like Isaie Bloch and Nendo (featured in the global survey *Digital Handmade* [11]), and uses Digital Craftsmanship as a combining method where traditional craft and digital workflows are fluctuating constructs of techne and poiesis.

Fig. 2. Cast glass doppelganger and original deer pelvis bone, *Augmented Fauna*. (© 2017 Tobias Klein)

Augmentation—Sublimation

Glass casting's ability to duplicate a found object with a high level of detail and surface precision became the departure point for *Augmented Fauna*. I worked with three different setups of casting glass. The goal of the first experiment was to replicate the original object in glass (Fig. 2). Using the traditional method of casting, my full-time technical assistant Phirak Suon made a silicone mold, which we used to make a wax replica of the pelvis bone. Afterwards, the wax cast was used to make a second mold using silicate and plaster. The second mold with the wax model was fired in an oven at 300°, burning out the wax and leaving a cavity for the glass to be cast into. This process is called investment casting as the mold breaks when removing the cast glass and thus cannot be reused.

The second cast was digital instead of physical. I transferred the physical found object from its solid state to a digital data construct using structural light 3D scanning. I used a HP 3D Structured Light Scanner Pro S3 [12] including a turntable setup that allowed for a continuous 360° scan. After automated stitching of the individual scan sections, this created a digital copy of the glass cast and the original pelvis bone. Using structured light scanning, I achieved a surface derivation between the original and scanned surfaces of around 0.05–0.1 mm. The digital copies became sites for the prosthetic argument. I developed the prosthetic construct first by deciding on reference mesh areas on the surface of the scans. Those anchor areas were the basis for a series of mesh and subdivision modeling operations using 3DS Max 2016 [13]. I used the bridging software tool to sculpt a rough connecting volume between the areas and a series of interconnected tendril-like substructures, attached to the emerging mesh. Lastly, I applied topological surface mesh modifications (push, pull, extrude, subdivision modeling, etc.) to the resulting mesh, imitating the natural growth of the bone substrate.

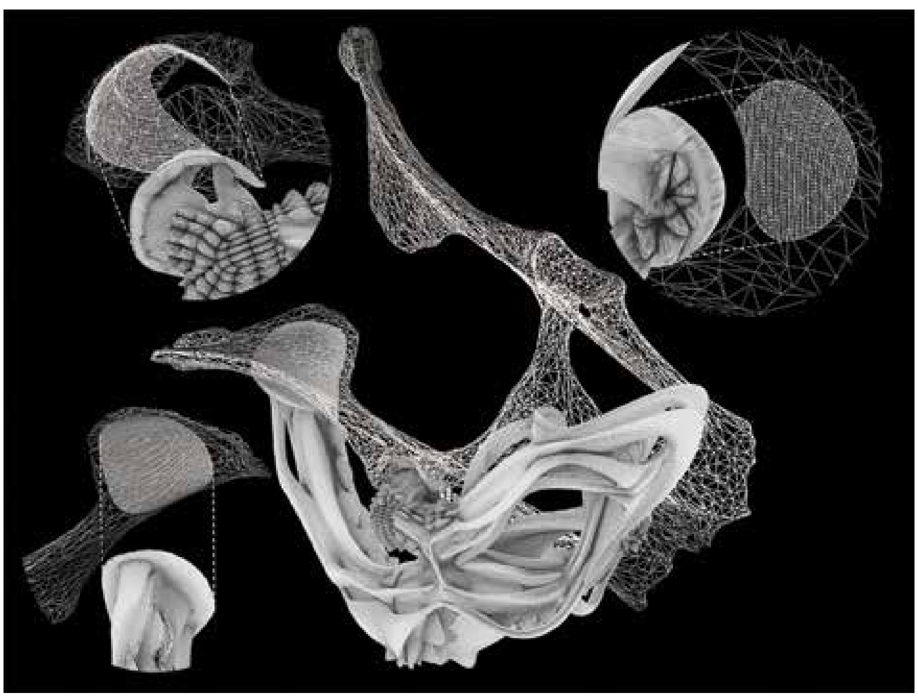

Fig. 3. 3D scan data of pelvis bone with reduced mesh count, 3D print prosthesis and high resolution mesh attachment points, *Augmented Fauna*. (© 2017 Tobias Klein)

The translation from actual to digital formed a tectonic intervention through fitting of the 3D-printed geometry grafted onto the scanned pelvis geometry, attaching it in three points (Fig. 3).

The last cast was similar to the investment cast, but involved 3D-printed substrate instead of wax. After 3D modeling of the additional prosthetic around the 3D-scanned digital copy, we printed the element using a fuse deposition-modeling printer. The printer was set up for the printed object to have a low internal density using a 3D honeycomb structure and a dense, precisely articulated, outer shell/surface. This allowed for a faster and cleaner burning out of the 3D-printed substrate (a thermoplastic with a low melting point) and a higher quality surface finish in the resulting glass cast. We used a Flashforge FDM 3D printer [14] with a Polylactic Acid (PLA) biodegradable thermoplastic derived from renewable resources.

Fig. 4. Glass cast pelvis bone with 3D-printed prosthetic augmentation and pelvis bone with glass cast prosthetic augmentation, *Augmented Fauna*. (© 2017 Tobias Klein)

Augmented Fauna (Fig. 4) consists of two geometrically identical objects, each using all three methods of casting. Each generated an otherwise impossible situation for traditional craft by adding a secondary loop—or meta-conversation—between the original and the augmented object, exchangeable with its copy. The first is a construct containing a 3D-printed prosthesis grafted onto the glass doppelganger of the original pelvis bone. The second assemblage is identical in geometry, but retains the original pelvis bone augmented by a glass cast of the 3D-printed prosthesis. The work articulates a clear relationship between digital and traditional craftsmanship tools and processes used in its making, a comparison between 3D scan as immaterial materiality and the investment casting of resulting 3D-printed objects in glass. The dialogue between the two pelvises and their grafted prosthesis opened new narratives about the notion of the material involving physical and digitally shaped processes.

In the process of casting, and especially during the burning out of the 3D-printed PLA, fractures occurred and the process needed to be repeated. In addition, bubbles were trapped in the glass as the glass could not flow through all parts of the element and rendered the first cast almost useless. Thus, while using digital tools as a method of scanning and creating a reversed cast proved successful, the direct translation of digital materiality in the form of casting failed.

Numerous elements that are not part of 3D printing but feature in the process of glass casting require fine-tuning and balancing—notably the firing temperature, the making of the plaster/silicate mold, the amount of glass used for the cast, and the extra amount on top of the cast in order to add pressure so that the glass would fill the burned out cavity in the mold—and were neglected during the modeling of the prosthetic element. The almost immaterial qualities of a 3D-printed substrate allow for more detail but, compared to traditional glass casting, must follow different rules to achieve high fidelity parts.

The most successful part of the experiment was the digital modeling of the 3D-scanned surfaces and the recursive processes that allowed for the formation of connections between scan and object through sublimation of the physical bone and resulting glass objects. The emerging objects therefore pointed out the limitations of a direct methodological transfer from cast to 3D print via scanning sublimation processes: augmentation is a process that left the initial body visible and grafted with an alien element that imitated material- and making-processes.

Amalgamation—Reification

For the second body of works, *Glass Mutations,* I had the support of Sasha Tepper-Stewart and Lisa Piaskowy, two highly trained glassblowers (also known as gaffers). The work consists of a series of evolving,

Fig. 5. Spikes are added by pulling heated parts from the glass surface. These node points are clearly identifiable in the 3D scan. They are geometric interface points for the 3D printing, *Glass Mutations*. (© 2017 Tobias Klein)

simple, glass-blown volumes that gradually increase in geometric, interconnected and material complexity. The formation processes of a glass object using blowing techniques are very short in comparison to casting. Molten glass is taken out of the furnace on a blowpipe. Immediately, the material is cooling down and changes viscosity from a liquid to a rigid state. The molten material is centered on the blowpipe using continuous rotation. The glass craftsman blows air into the blowpipe to inflate the glass. More glass can be added and various rotational shapes can be made. Lastly, the object is finished through multiple reheating of the glass in a stationary oven, maintaining the material's plasticity and thus allowing shaping of the object with blocks, jacks, paddles, tweezers, newspaper pads and a variety of shears.

Glass Mutations is based on the concept of the primordial in cell mitosis. The process of mitosis occurs when cells split and build more complex organisms. The work extends this idea—the beginning of all complex life—and applies the residence theme of Taxonomy to an argument centered around the notions of evolution and mutation. By adding digital processes into the otherwise predictable sequential developments of the glass objects, the mutation starts at the surface. Deforming the glass surface by pulling it locally, we created geometrical anomalies that became attachment points and, ultimately, interfaces between the glass, 3D scan and printed object (Fig. 5). They enable Cartesian recognition in the 3D scan and, later in the assembly of print and glass, mechanically hold the 3D-printed elements in tension.

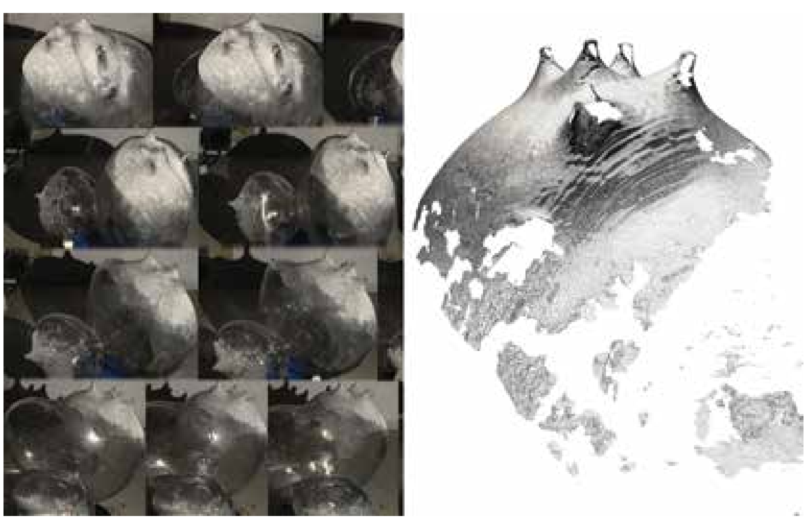

Fig. 6. Collage of automatically generated mapping data from the 3D scanning with resulting polygonal mesh and areas where reflection and refraction made scanning impossible, *Glass Mutations*. (© 2017 Tobias Klein)

Differently from the scanning of bone or cast glass in *Augmented Fauna*, the reflection and refraction of the glass did not allow a simple 3D scanning process [15]. This problem also occurs with traditional photography of glass objects where it is impossible to use the autofocus function of cameras or when the photographer deals with unwanted reflections from the studio. We designed a method to dull the reflective material property while retaining a high geometric precision by using a structured light scanner with a camera recording the pattern deviation on the surface of an object to generate 3D geometry. While in photography, hairspray is used to take away the reflection, we used a combination of hairspray and gypsum powder to allow for the projected patterns from the structured light to be recognized by the camera. This in turn allowed the software to apply photogrammetry algorithm and ultimately created a 3D model of the glass objects (Fig. 6).

Following the resolution of the scanning issue, we added further geometrical complexity by increasing the number of glass volumes. However, when adding a third volume in the glass blowing process, the linear development from single cell mitosis collapsed on multiple levels. In biological terms, mitosis would not be able to occur with three cells involved on a regular basis. Similar to cancer, where certain cells are able to split into more than two daughter cells [16], the work started to enter the territory of mutation rather than that of evolution based on repetition. In terms of craftsmanship, the added third volume destabilized the overall form and making process. The object was not a rotational form anymore and was therefore off-centered. It had multiple axes and all craftsmanship processes became so difficult that up to six helpers were needed to do the transfer from a single blowpipe to two blowpipes. Testing how far this type of unnatural approach—in both the biological and craftsmanship terms—could be taken, we created an interconnected four-volume object. Highlighting this spatial complexity, the volumes were completely evacuated and filled with neon gas. The gas was ignited through electrical charge and subsequently the gas illuminated the shortest path with the least resistance through the volume and between the two electrical poles. As glass is electrically isolating, the shortest path led through the four volumes. At points of smaller diameter, the light was more intense due to the higher density of ionization and thus illumination (Fig. 7). This showed the most extreme state of mutation in the work series, but it lacked the formal and methodological amalgamation between scan, 3D print and glass.

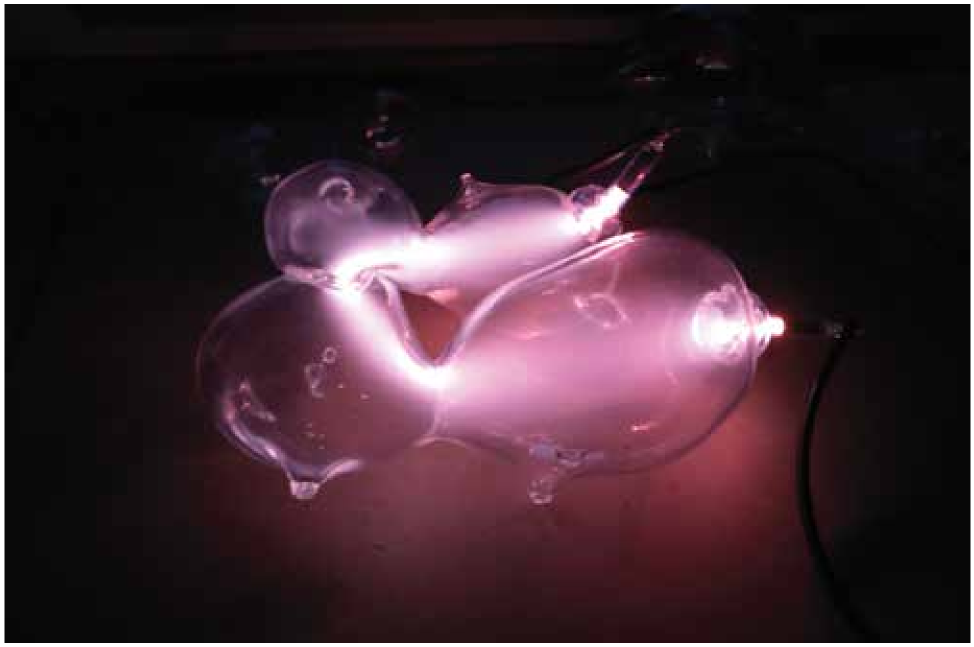

Fig. 7. Electrically charged neon gas illuminating an interconnected 4 volume glass cell, *Glass Mutations*. (© 2017 Tobias Klein)

As a consequence of working against the glass material behavior, we had several failures in the making. The forms were not controllable and broke off the blowpipe, fell in the furnace, fell during their transfer, or became too difficult to handle for a team of two glassblowers. In hindsight, these failures were unexpectedly fortunate learning experiences emerging from this project. They allowed us to rethink the relationship between 3D-printed and glass blown form.

Glass Mutations is not a work centered around the geometric complexity of glass and the imitation of the formal impossibilities of 3D printing. *Glass Mutations* is an amalgamate of glass volumes held in a larger organism-like construct through 3D-printed substrates. Differently from the augmentation experiment—*Augmented Fauna*—the new objects are not static and conclusive in themselves, but rather suspended in an arrangement that can only exist in a 3D-scanned state of sublimation. This work consists of the physical separation of the cellular glass volumes from one another and the 3D-printed form interacting with these single objects to form an ecosystem between the glass volumes. The elements are held together by digitally modeled, tendril-like structures, analogous to biological cell growth when forming multi-cellular higher-order organisms. When observed as a series (Fig. 8), *Glass Mutations* constitute a Biotope of craft, material and forms. Individually, they are comparable to the surface of cellular organisms like the radiolaria depicted by Ernst Haeckel [17].

Fig. 8. Two of the final works in the series, installed at the Industry Gallery in Los Angeles, U.S.A., *Glass Mutations*. (© 2017 Tobias Klein)

Conclusion

The process of fusion/synthesis outlined in *Glass Mutations* summarizes how "Sublimation"—the process of 3D scanning enabling the melding together of glass and the 3D prints—and "Reification"—which is the form of bringing the data back in 3D print—create complex life-form–like arrangements. In other words, whereas augmentation is a form of imitation, amalgamation is a process of inseparable fusion that, in the case of the series of pieces I created at Pilchuck Glass School, allowed me to articulate the notion of Digital Craftsmanship.

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