The Ghost in The Machine

Digital Stylization and Expressive Re-Materialization of Ancient Ceramics

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This paper proposes a new perspective on the role of computers in the re-materialization of ancient artifacts, highlighting issues of conservation, self-expression, and authorship in creative processes. Specifically, our approach allows all of the creative spirits (i.e., creative agencies) taking part in the making process—from the ancient makers, to the digital craftsperson, to the making machine itself—to be represented in the final outcome. The paper explores the evolution of our technique through three projects that rely on both digital and traditional making practices. We introduce the notion of a digital spirit, which allows for a holistic and respectful integration of diverse making agencies in a unified hybrid practice.

CCS Concepts: • **Applied computing**; • **Arts and humanities**; • **Fine arts**;

Additional Key Words and Phrases: Digital Craft, Hybrid, Ceramics, Fabrication

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1 INTRODUCTION

This paper presents three art projects in which we re-materialized ancient ceramic objects from 3D scans using CNC milling of wet clay and plaster molds as well as traditional ceramic processes. In these projects, we reproduced the form of the ancient artifacts almost verbatim, while treating their surfaces as the main realm of creative exploration—a canvas, if you will, for the hybrid orchestration of a physical-digital creative process. Surfaces have been historically considered a highly significant space for artistic expression, yet these aesthetic traditions have hardly informed digital fabrication in the fields of art and design [Carr, 2020; Hopper, 2016]. The potential of 3D objects' surfaces has largely been overlooked by the designers of Computer Aided Design and Manufacturing (CAD/CAM) systems and, therefore, by artists using these technologies. We identify the surface of digitally fabricated 3D objects as a space that offers great potential for self-expression and have built new digital tools to explore that potential. By altering objects' surfaces, we diverge from the practice of simply conserving or digitally reproducing ancient objects. Instead, we embrace an artistic practice in which ancient artifacts serve as an inspiration and a formal foundation. While

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we change the objects drastically, our method weaves together the spirit of the ancient source, the collective intelligence embedded in the machines we use, and our own personal expression.

A digital making process is a superposition of the human and non-human agents that have contributed to, and thus shaped, a given product. This may include software designers, mechanical engineers, the milling bits and tools used, and so on. Together, these contributors create the environment in which making takes place, and collectively constitute what we call the *digital spirit*, which encapsulates all the agencies involved in a digitally informed work. Taking up Zoran et. al.'s call to "advocate for a medium that unifies the physical product with the spirit of the making process," [Zoran et al., 2021] our projects demonstrate creative processes in which a digital making machine can be considered *a collaborator* with autonomous agency.

In introducing the concept of a digital spirit, we echo traditional craft practices in which various tools and players operate together to achieve an orchestral composition. For example, in some Japanese pottery traditions, potters regard a wood-fired kiln as a "partner in the decorative processes" [Jones, 2016]. The potter firing such a kiln sets certain parameters, but also relies on the complex and somewhat unpredictable dynamics of the fire and ash deposits to color and glaze the pottery. In this way, the kiln apparatus (or kiln *spirit*) determines a significant part of the design. In contrast to the chaotic nature of ceramic wood firing, digital fabrication processes are controllable and predictable; their deterministic operation limits their agency to the role of *producers*, rather than *artistic collaborators*. And yet, even under the most restricted and controlled settings, digital systems contribute a characteristic, mechatronic style [Kemper and Cypess, 2019]. In this paper, we offer a new perspective on the expressive potential of digital processes by cross-pollinating digital and traditional methods of ceramic art making. Such a hybrid practice enables us to highlight the creative potential of the making agency, rather than its technical function alone. In what follows, we outline the evolution of our technique and offer tools and principles for future hybrid practice.

2 RELATED WORK

CAD/CAM technologies have revolutionized craft processes and popularized computational making practices [Johnston, 2015]. Museums and archaeologists are using 3D scanning to document and publish ancient artifacts in high resolution. The convergence of a growing database of 3D scans and the availability of digital fabrication systems creates new opportunities for artistic exploration and new ways to relate to cultural icons [Wenman, 2021].

Reproductions of ancient works of art go back to antiquity itself [The Metropolitan Museum of Art, 2002], but the introduction of high-resolution digital scanning and fabrication has enabled reproductions of unprecedented scale and precision. Most notably, The Factum Foundation for Digital Technology in Conservation [Factum Foundation, 2022], which promotes technology-based conservation and documentation of world heritage, has developed innovative digital methods to reproduce highly accurate facsimiles of not just objects but entire structures. For example, the foundation produced 1:1 scale facsimiles of landmarks such as the tombs of Seti I (2017) and Tutankhamun (2014) in Egypt, thus creating alternative ways to experience these works, while reducing the damage to the originals associated with extensive tourism.

More recently, Stratasys, a manufacturer of 3D printers, presented *Not Made in China* [Benyamini Contemporary Ceramics Center, 2020], a series of plastic replicas of ancient Chinese ceramics. Stratasys used 3D scans that are available on the Smithsonian Institution's website. The replicas mimicked the color and smoothness of Chinese porcelain so successfully that only by holding them could one notice their plastic materiality [Benyamini Contemporary Ceramics Center, 2020].

Far from restricting themselves to producing exact facsimiles, artists have also been using digital strategies to re-materialize artifacts while creatively intervening in the process. For example, in his project *Other Histories* (2018), Bryan Czibesz scanned historic monuments and later re-materialized sections of them using clay 3D printing [Czibesz, 2020]. Czibesz manually poured colored slips and manipulated the clay as it was printed, thus generating an expressive hybrid of hand/machine work.

In 2018, a fire devastated the Museu Nacional in Rio de Janeiro, Brazil. In collaboration with the museum, Belgium-based studio Unfold [Unfold Design Studio, 2021] initiated *The Atlas of Lost Finds* (2020–present), for which they invited makers to re-materialize an ancient Peruvian vessel from the lost collection. Participants received a 3D scan of the original object and were asked to use their personal style and techniques to collectively explore what a meaningful digital re-materialization might be. Our contribution to this project will be presented later in this essay. Despite being an artistic rather than a scientific project, *The Atlas of Lost Finds* exemplifies the potential of high-resolution scans to help recover artifacts lost due to natural disasters, wars, or iconoclasm.

3 TECHNICAL BACKGROUND: THE SURFACE'S EXPRESSIVE POTENTIAL

August Rodin eloquently captured the creative potential of surfaces when he wrote, "The sculptor must learn to reproduce the surface, which means all that vibrates on the surface, soul, love, passion, life. . .. Sculpture is thus the art of hollows and mounds, not of smoothness, or even polished planes." [Gardner et al., 2005] In our creative approach to re-materialization, we maintain the object's form and focus on the surface as the primary space for intervention. We attend, in particular, to the way that artworks' manifest personal expression and style through texture, color, and surface complexity. Because surfaces carry evidence of the action of making, they convey significant information about personal style [Dick and Zoran, 2019], [Zoran et al., 2021]. Computationally, surface marks can be analyzed to identify an object's maker [Glauber et al., 2020], [Case Western Reserve University, 2021]. The importance of surfaces is similarly highlighted by producers of facsimiles; for instance, the Factum Foundation meticulously reproduces texture and color since these fine details render the high fidelity of their facsimiles.

To fabricate complex and expressive surfaces, we developed tools to feed the system with information that extends the design of three-dimensional forms. Existing CAD/CAM applications enable 3D scans manipulation, and fabrication, but usually offer a very limited set of standard finish operations. These applications are designed to maximize precision and efficiency—features that are crucial for producing facsimiles, but may be less relevant for modes of artistic production in which variable depths and irregular patterns are highly desirable. In traditional art making, such features are important means of expression that carry meaning and evoke emotional responses. We thus sought to develop methods to create expressive surfaces using subtractive manufacturing, the most important of which is a custom toolpath generator developed in Grasshopper, a parametric design plugin for Rhino3D.

In the projects presented here, we used 3D scans to design molds using Rhino, which were then milled out of plaster using a CNC milling machine. In the first two projects, *Archi-Numeri* and *Kylix*, we created complex surfaces on the molds. In *Felideo*, the mold was only used to cast an approximation of the form, and the expressive surface was fabricated by digitally carving the moist clay cast itself. Wet clay is malleable, hence the computerized cutting tool not only removes material, but also pushes it in ways that cannot be fully controlled. Moreover, the machining process might take a few hours, during which time the clay dries and shrinks, changing its geometry as well as its machining qualities.

We considered both these effects an advantage precisely because they added an element of uncertainty to the system and required the maker to be fully in tune with the machine throughout the process. In this context, being in tune with the machining process means making spontaneous adjustments or even allowing the process to continue when it clearly diverges from the plan. Within this mode of production, fabrication becomes a hybrid human-machine operation, even though there is no manual handling of the clay itself. Moreover, adding non-linear elements to digital fabrication resonates well with David Pye's notion of "a workmanship of risk" or the unpredictable quality that he defines as the core of craft practice [Pye, 1968], represented here as the agency carried by the digital spirit. Finally, although the objects we created were digitally fabricated, our manual interventions made them practically impossible to reproduce. They are thus, simultaneously, mechanically reproduced and one-of-a-kind, echoing traditional artistic production.

4 RE-MATERIALIZING ANTIQUITY

This section presents the specific techniques we developed and the context of each of the three projects. We explain how we generate non-standard machine operations, and discuss how our approach enables a creative dialogue between a maker and an automated system

4.1 Archi-Numeri

Archi-Numeri is a series of works based on 3D scans of ancient vessels dated 10^{th}–8^{th} century BC that were excavated in Israel and scanned by the Computational Archaeology Laboratory at the Hebrew University of Jerusalem. In this series, we integrated digital technology and traditional methods to fabricate highly textured ceramic surfaces to enhance ceramic glazing effects. Thus, each of these objects embodies how artists have used technology throughout history to develop new aesthetic expression. Given that traces of the digital realm are highly ephemeral, these objects serve as quintessential manifestations of contemporary technology and may function, similarly to archeological findings, as archival markers of our chronological and cultural era.

The ancient vessels were the formal and spiritual anchors of our digital work. Formally, the scans served as the starting point of our design. We relied on viewers' familiarity with the vessels' archetypal forms and materiality to draw their attention to the newly designed surfaces. As mentioned earlier, these works demonstrate the unique role of surfaces as a space for innovative digital expression. To achieve the desired surface qualities, we began by generating a set of standard machine operations. We then collaborated with the machine by watching the process and manually intervening in it. For instance, we terminated one operation before completion and immediately started a new one, which allowed us to change pattern and resolution by dynamically responding to the visual cues the machine provided. Additionally, we designed a custom tool-path generator that produces machine operations with non-uniform resolution and complex patterns [Figure 1]. The fabricated textures function as a decorative pattern and influence the glaze dynamics in the kiln; for example, coloring textured "valleys" in dark green and "ridges" in light green. The result is a synergy between contemporary technology and traditional techniques.

4.2 Kylix

Kylix was developed for *XYZT Investigations*, an exhibition that explored contemporary technology in archeological research as well as artistic responses to digital archeology. We chose to re-materialize a kylix made in Cyprus and dated 1150–950 BC, using a 3D scan by the Computational Archaeology Laboratory [The Institute of Archaeology, 2022]. The original object was eventually displayed alongside our digital interpretation of it. Our goal in this project was twofold: first, to further explore the aesthetics of non-standard machining patterns; and second, to expose the unique aesthetics of digital scan representations. We consider these representations to be quintessential manifestations of the "digital spirit" since they are the most fundamental and abstract objects we work with. We therefore derived the surface directly from the scan representation, expanding its role from that of an abstract manifold to a concrete set of production directives. The kylix scan is a 3D mesh—a set of vertices and connecting edges. Our algorithm defines a path by selecting

Fig. 1. Archi-Numeri Complex surface patterns induce glaze variations. (Photograph ©Asaf Oren)

Fig. 2. Various versions of *Kylix*. Right, standard parallel finish. Middle, surface decoration by a mesh-derived toolpath and a sharp conic cutting tool. Left, the same toolpath using a 1/4-inch ball-nose cutter. (Photograph ©Asaf Oren)

sequences of connected edges iteratively. At each iteration, one neighboring vertex is added either randomly or by minimizing the path deflection angle with respect to the previous step. Each vertex can be added only once. The path is completed once a dead-end is reached, or when the number of steps reaches a limit. Paths are added until no vertices are left with free neighbors. Eventually, all paths are connected to a unified toolpath.

Three parameters control the final design: maximum number of steps, cutting tool geometry, and mesh resolution. For example, we used a ball nose cutter to create soft coral-like texture and a sharp conic tool to generate a more energetic line quality. The resulting surfaces are clearly different [Figure 2]. In contrast to the ubiquitous usage of multi-faceted surfaces to signify the digital origin of an object, we utilized the mesh aesthetics to generate a surface pattern. The interplay between the control parameters enabled us to achieve a variety of patterns that represent the polygon mesh but visually diverge from common representations of meshes in contemporary design.

4.3 Felideo

Felideo is based on a vessel from Peru's Chimu culture dated to the 10^{th}–15^{th} centuries, which was damaged, but survived the devastating fire at Brazil's Museu Nacional. More than forty artists responded to studio Unfold's call to re-materialize this vessel from a 3D scan the museum acquired prior to the fire. The ancient design is dominated by a figurative animal face, which inspired us to develop a digital interpretation of manual sculpting. Similarly to sculptors, we used different methods to fabricate the large features and the finer details. To reproduce the general form, we fabricated a mold using standard machining [Figure 3]. Our intervention yet again focused on the object's surface, for which we designed a unique machine operation that loosely mimics manual carving. Carvers commonly apply short strokes that are tightly dependent on the form they intend to render. We hypothesized that these strokes are dominated by two considerations: first, carvers clusters their strokes around semantically distinct parts, such as an eye or a mouth; second, for manual carvers, changing the direction of the stroke is complicated and unnatural. Hence, a sharp change in the underlying geometry would result in shorter strokes, whereas smooth, larger areas would yield longer strokes.

In contrast, standard machining covers the form with a simple geometric pattern (most commonly, parallel lines), and completely ignores form semantics and local geometric qualities. To integrate manual carving qualities into our machining process, we used the algorithm we developed for *Kylix* while controlling the mesh resolution and length parameter. This process generated a set of strokes directly derived from the form itself. To localize the strokes, we set the maximum stroke length to be relatively short and added the strokes to the unified final toolpath based on proximity. To achieve the nuanced differences in stroke lengths that characterize manual carving, we took advantage of some typical qualities of 3D meshes where polygons are rarely uniform. Large, smooth areas are modeled using fewer, larger polygons, whereas areas with complex geometry are modeled with many smaller polygons. Thus, a ten-edges long path in a smooth area will be physically longer than ten edges of a dense mesh. Moreover, since we minimized the deflection angle between steps, we satisfied the requirement to generate strokes that follow the form in a more natural way.

Finally, we milled the clay while still moist, allowing the machine to interact with the material. The clay was not only removed but also pushed in some unpredictable ways, generating complex patterns. The resulting aesthetic is not fully algorithmic, but rather a reflection of an interaction between the virtual and physical worlds [Wegner, 1997]. Coupling high-precision equipment with a non-linearly changing material like wet clay created a very productive environment for us to collaborate with the machine. We created a process through which the machine felt like an extension of our own bodies, making the final product simultaneously, and paradoxically, personal and mechanical [Figure 4]. We found the bare carving patterns rich and evocative, and thus decided to leave them unglazed.

5 SUMMARY

Although materiality is critical for artistic production, it is mostly disregarded in CAD/CAM systems. We show that adjusting fabrication processes to specific materials is crucial for achieving a new aesthetic expression. Moreover, instead of treating fabrication as a collection of unrelated technical procedures, we introduce the notion of "digital spirit" to capture a holistic interaction with the digital system as a creative collaborator. Considering the machine as a collaborative agent generated a creative space in which we could rely on our extensive experience with clay, glaze, and traditional ceramic techniques without the burden of strict modeling and complex engineering. As such, we also acknowledge that we are not the sole creators of the work and respect the contributions of other creative forces present. We argue that this mode of operation combined with enhanced control

Fig. 3. Form approximation using standard machining (right and middle) and post-digital carving (left). (Photograph ©Alexandra Dvorkin)

Fig. 4. Expressive machining; custom toolpath machining in wet clay. (Photograph ©Asaf Oren)

of surface operations will allow artists to better utilize their profound knowledge of materials. This knowledge will, in return, better inform and enrich digital fabrication. Finally, the intersection of a growing database of high-resolution scans of cultural heritage objects and the proliferation of robotic fabrication systems creates an exciting space in which to develop new tools for artists, engineers, and conservationists.

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