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# Design with Minimal Intervention: Drawing with Light and Cracks

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## Abstract

Industrial design focuses on minimizing fabrication variability, aiming for identical products, while craft practice often results in unpredictable outcomes. We rely on crackle, an explicit pottery phenomenon that renders a pattern of cracks in ceramic glazing, to produce craft-unique outcomes in a moderately controlled design process. With the help of a dedicated CAD tool and a laser machine, we embed artificial decorations in a crackle pattern. By pre-processing the clay and post-processing the glaze, we demonstrate a technique to partially control the typical size of cracks in a given area, thus embedding visual forms in the glaze.

## Author Keywords

Glazing; Crackle; Craft Laser; Hybrid; Computer-Aided Design (CAD); Ceramics.

## ACM Classification Keywords

H.5.2. User Interfaces: User-centered design.

## Introduction

The study of *hybrid craft* offers a creative territory where designers mix production paradigms, techniques, and tools to enrich creative practice [26]. Digital fabrication technologies, such as 3D printers and laser cutting machines, join manual practice and analog craft technologies to allow for new creative affordances.

**Figure 1:** Four ceramic tiles with crackles, displaying a decaying Hebrew text from the Kabala using laser-induced crackles (PaRDeS). From right to left, in Hebrew: Peshat (פשט)—"straight"; Remez (רמז)—"hints"; Derash (דרש)—"inquire"; and Sod (סוד)—"secret." This text is ignorant of the pattern grid and was enforced brute-force, unlike other work presented in this paper.



In addition to the technical prosperity, the hybrid medium allows for two distinct attitudes to co-exist. *Craft* is a territory of unpredictability and engagement [21], where the qualities of the final outcomes are hard to predict or guarantee [19]. Digital fabrication relies on well-defined, engineered processes, resulting in minimal production error with respect to preliminary design [8]. Thus, the hybrid medium allows makers to enjoy the automation, precision, and control enabled by digital tools, while preserving process unpredictability and artifact uniqueness [6,26,28].

We offer a hybrid method for ceramics decoration (see Fig. 1-5), which relies on a pre-existing natural pattern. A pattern is *a repeated decorative design, an arrangement or design regularly found in comparable objects* [18]. Visual patterns are widespread in art and nature [9], where the latter are seen as chaotic, never repeat exactly, and often involve fractals [22]. Patterns have an underlying mathematical structure of various types of symmetry, which makes them relatively easy to detect with the human eye. Naturally made patterns tend to share geometric similarities, such as the veins of plant leaves, which exhibit a topology corresponding to tensorial stress field that result in a grid of cracks [4]. Furthermore, patterns are widely popular in generative and parametric design, as a result of their basic mathematical structure and organization [20].

We aim at using the natural process of pattern generation with only minimal pre-and-post production intervention. Working in the realm of ceramic glaze crackle, we rely on placing a few elements of the naturally generated pattern into the service of artificial design. Hence, we contribute a concept of *Design With Minimal Intervention*, where naturally produced patterns are manipulated to

satisfy decorative requirements, without the need to manipulate every detail of the generated pattern.

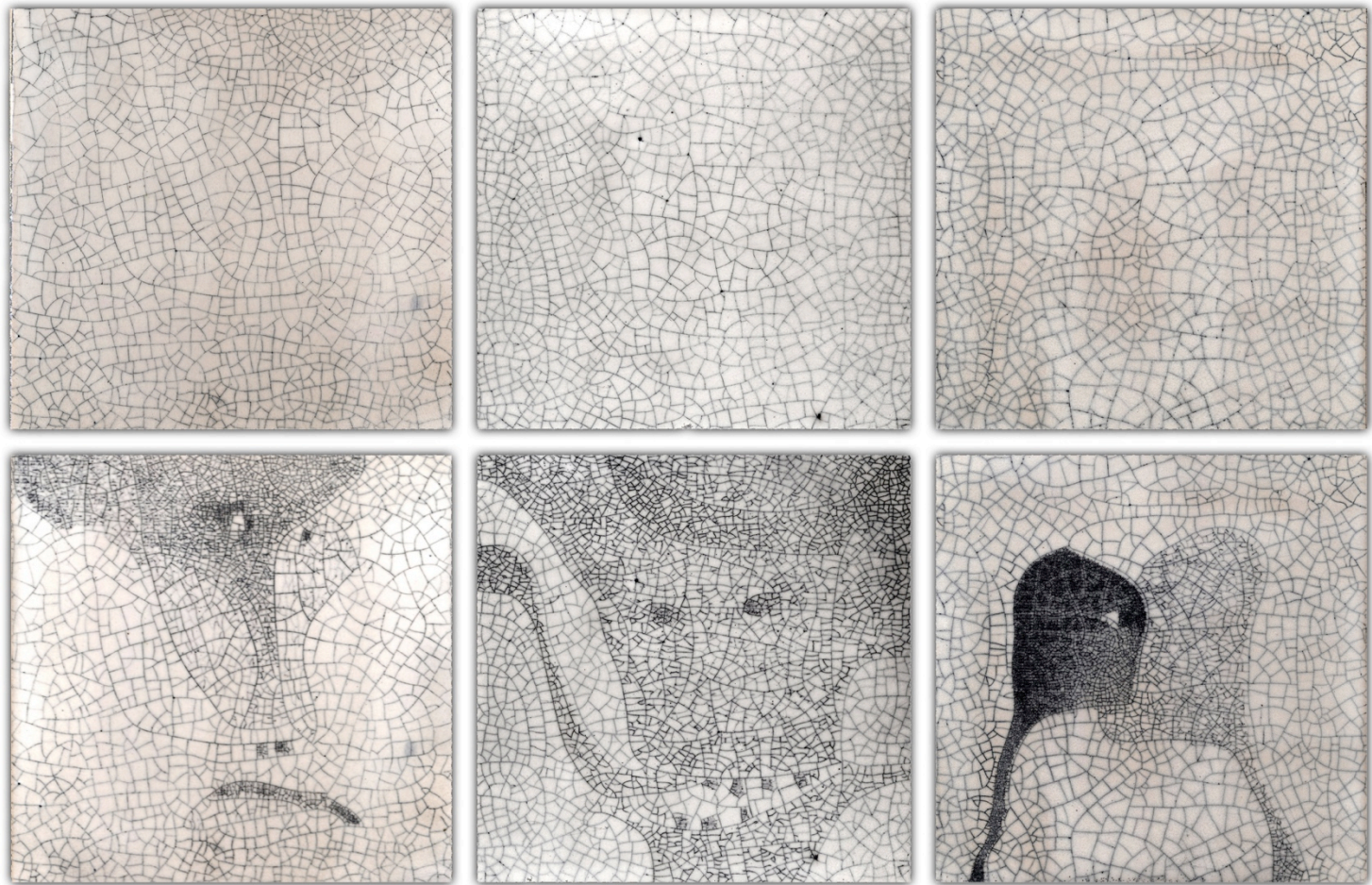
In this work we focus on the grid of cracks that appears in ceramic glazing, called *crackle*. We contribute a technique to control the density of natural crackle patterns in ceramic glazing, employing their physical and environmental singularity to serve an artificial design process. Our technique consists of two stages. First, by pre-processing the glaze thickness and orientation prior to firing, we partially control the density and orientation of the crackle pattern. Then, using a laser-cutting machine, we apply localized energy inputs into the glaze, resulting in a higher density of cracks in specific areas (see Fig. 1-2). The outcomes demonstrate decorations made using our hybrid design process. In addition, we present a *computer-aided pattern-detection* (CAPD) tool that highlights structures in the natural crackle pattern, thus supporting a design process that relies on pre-existing generated forms and shapes.

### **Related Work**

The application of contemporary digital fabrication developments [8] to craft and traditional practices holds a promising creative potential. This hybrid medium is the topic of many CG, HCI, and design studies [2,3,6,13,25-28], and some of these projects have used laser cutting to draw craft guidelines [7] or prepare hybrid work [12].

In HCI, researchers have explored alternative ways to interact with laser cutting machines, such as LaserOrigami [15]. Laser techniques for ceramics are still quite rare, with a few exceptions. Mia Mulvey used a laser cutter to cut thin porcelain sheets in various butterfly shapes [16]. In a previous project, we also used a laser cutting machine to alter ceramic glazing in diverse ways,





**Figure 2:** Three ceramic tiles with laser-induced crackle figures (bottom), evolved from a pre-existing natural crackle pattern (top).

such as using a laser to melt glaze powder post-firing then washing the rest of the glaze powder, or post-processing fired glaze to alter its color.

We are not familiar with any prior work on laser-induced crackle, although Nam et al. [17] demonstrated controlled initiation, propagation, and termination of a variety of channeled crack patterns in a film/substrate system. In CG, researchers have studied methods for generating (virtual) surface crack patterns, such as [11], demonstrating the aesthetic potential of crackle-related digital work.

### **Background: The Generation of Crackle Pattern in Ceramic Glaze**

Ceramic glazing is a traditional technique for coating clay objects with layers of vitreous enamel. Glazing is used to waterproof, color, or ornament ceramic items and results in a vast selection of surface texture and pigment options [23].

Since both clay and glaze shrink while firing, if their shrinking coefficients vary significantly, a tension will evolve over the glaze and ceramic surfaces, which may result in a pattern of cracks in the thin glazing layer. In other words, cracks in the glaze appear when there is some inconsistency between the clay body and its layer of glaze. The glaze shrinks and stretches during its whole lifetime, from the initial firing through later use of the object. These cracks can appear immediately after firing or over time as the artifact ages, resulting in a pattern called *crackle*.

Throughout history, different cultures developed different attitudes to the appearance of crackle in glazes [1,24]. Basically, crackle is a fault in the main function of the glaze—to cover the body of clay with a unified layer of glass. Moreover, if crackle evolves in the glaze, the object may not be watertight any longer, as the body of clay and the tiny gaps in the

glaze tend to absorb some of the materials coming in contact with the object. This phenomenon emphasizes the crackle over time and enhances the “defective” character of the object.

Yet, traditional Eastern cultures, mainly in Japan (with some Korean influence), developed a deep relation to crackle. Resting on the foundations of Daoism and Buddhism, an interest in the ever-present relationship between “defects” and the passage of time grew to prominence in these cultures [10]. Ceramic objects marked with crackle that changed color over time were honored, and artists developed the raku technique, which produces objects that are both damaged and complete. In raku, the clay object is taken out of the kiln when it reaches its maximum temperature, and cooled rapidly in the open air. This drastic process damages both the body of clay and the glaze, hopefully imbuing them with a balance between control and the lack of it.

Due to its philosophical charge and visual complexity, the aesthetic of crackle is relatively common. Usually the crackle pattern is colored with ink, or smoke (as in modern raku), but many other options exist to achieve this aesthetic. In the work being presented, for practical reasons, we used black India ink to color our crackle. We simply coat the crackled surface with ink, after cooling, and wipe it off with a wet rag.

### **Controlling Crackle Pattern in Glaze**

During the work, we experimented with and explored many types of clay, glazes, and designs, until we gained a sense of control and understanding of the process. We started out using small clay disks to study the density and orientation of crackle formation, then demonstrated the process on larger elements, including 3D plates.

#### *Manufacturing the Disks and Plates*

For the work presented in this paper, we created small disk-like plates (around 8.5 cm diameter), larger disks, (around 16 cm diameter), and oval 3D plates. All of them consist of a terracotta clay body glazed with a white crackle glaze. Each plate's body was hand-manufactured by a ceramist using the clay-slip technique, a standard technique used both by independent craftspeople and industrial companies.

In the first stage, a one-by-one model was made of plaster. This stage is characterized mostly by finding a balance between function and shape. After that, a plaster mold was made for the model. Next, the plates were cast by pouring clay-slip into the plaster mold. The plaster absorbs water from the slip in the intersecting area, creating a fairly stable shell of clay in the desired form. Finally, the clay bodies were fired at 1220°C. At this temperature, some of the terracotta clay ingredients begin to melt and seal the clay, so it absorbs much less liquid or organic material.

#### *Glazing the Disks and Plates*

Ceramic glaze consists of silica mixed with other materials that cause it to melt at a reasonable range of temperatures (below 1220°C) and obtain certain desired characteristics. The chemical mechanism used is the *Eutectic point*, where the melting point of the mixture of a few materials is lower than the melting point of some or even all of the other materials. More materials are added to obtain properties such as color, stability, and shrinkage. For glazing, we use a standard, low-temperature, white crackle glaze. Although the usual

recommendation is to fire the clay body to a lower temperature before glazing, or to use a high-temperature glaze [24], we did the work as described for practical reasons.

#### *The Crackle Pattern*

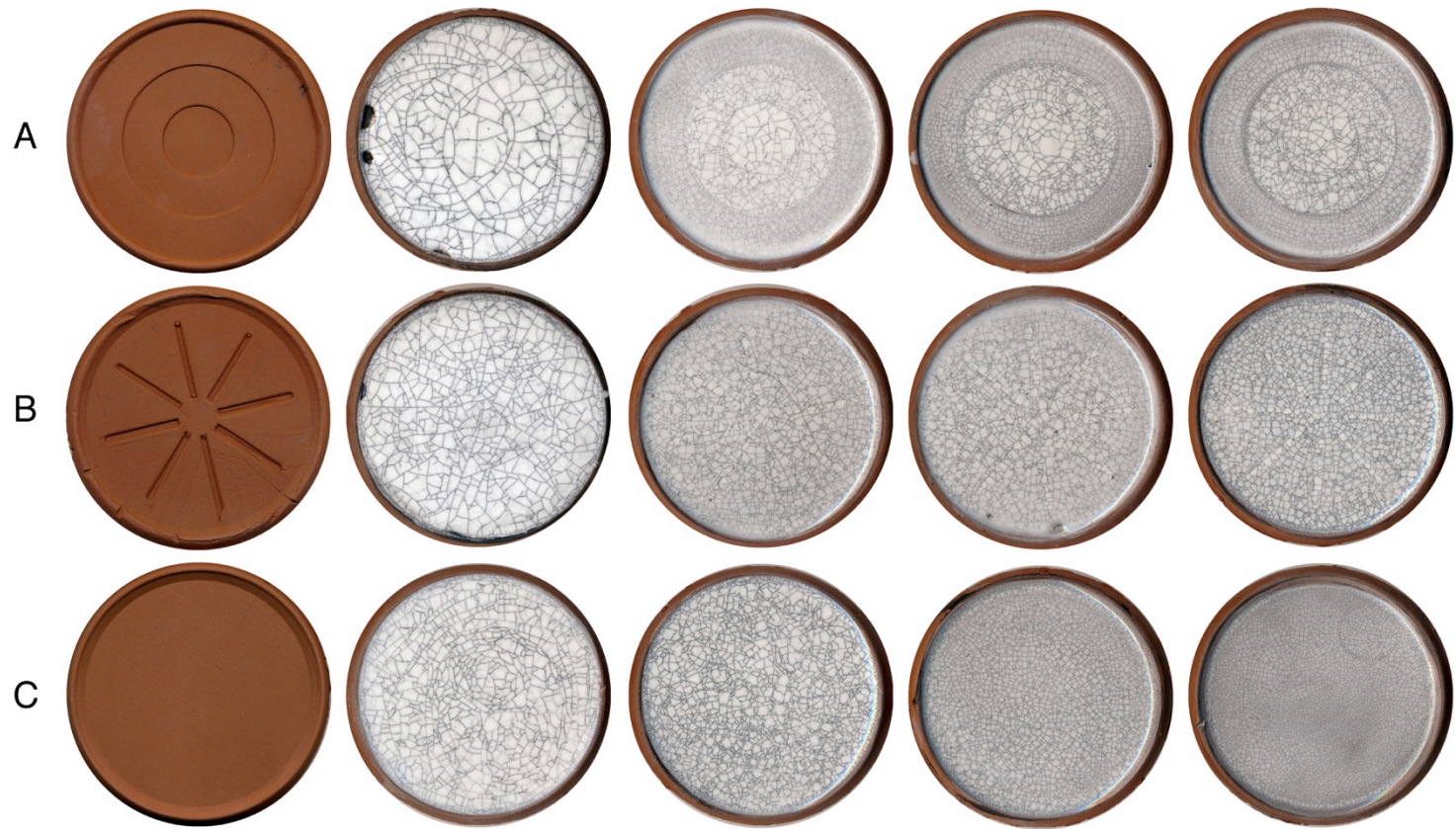
The glaze we used tends to crackle thoroughly and form most of its texture while cooling in the kiln. After melting and while cooling, the glaze shrinks over the relatively stable clay-body, being torn both by the shrinking and the friction with the clay.

A thick layer of glaze may result in wide areas of bald clay, since as the mass of glaze rises at some points, the friction between the glaze and clay becomes less effective, and the glaze moves more freely on the clay. By contrast, a thinner layer of glaze breaks into parts with a larger area, allowing us to manipulate the surface more definitively. Thus, we glazed each plate several times (approximately three). Each time, we added a thin layer of glaze and fired it to 970°C, until we reached the desired thickness of glaze, and thus the desired average area within each crackle.

#### **Crackle Pre- and Post-Processing Methods**

Having a certain amount of control over the crackle formation allows us to define visual decorations. We developed two methods for post- and pre-processing of the crackle. The first method is ceramic surface treatment, and the second is laser-selective heating of the fired glaze, both of which influence the crackle density. Crackle density can be mapped directly to gray-scale levels, as areas with more crackling receive more ink, and thus appear darker.





**Figure 3:** Impact of ceramic surface treatment and glaze thickness on crackle formulation. We tested three types of disks: (A) a disk consisting of steps; (B) a disk with 2 mm depression lines; and (C) a flat surface disk. The left disk in each column is the ceramic one with no glaze, four glazed disks with glaze thickness going from thick (almost 5 mm) to thin (almost 0.5 mm). Crackle resolution is a function of glaze thickness, while crack orientation is influenced by the surface treatment.

### *Ceramics Surface Treatment and Crackle*

#### *Orientation: Crackle Pre-Processing*

Laser heating can impact crackle resolution, yet the preliminary density and orientation of the cracks has a major influence on the potential of the laser to cause new cracks. Thus, we aimed at gaining some level of preliminary control over the initial crackle. In order to affect the characteristics of the crackle pattern in a way that best served our purposes later in the process, we conducted several experiments. To study the impact of glaze thickness and ceramic surface treatment on the crackle density and orientation, we manufactured two types of test disks.

First, we made small terracotta disks (about 8.5 cm) by pressing clay into a plaster mold. These allowed us to test glaze layers approximately 0-5 mm thick. We made three types of small disks: (1) disks with small circular steps on the ceramic surface (less than 1 mm each); (2) disks with several 2 mm depression lines leading from the disk center to the outside edge; (3) and disks with a flat surface (see Fig. 3). After glazing and firing, we concluded that the thicker glaze tends to crack into larger pieces, and more interestingly, when the thickness of the glaze changes rapidly, a crack that follows this change will occur. As the glaze gets thicker, this primary crack may not be fully aligned with the ceramic surface guiding details, but it will keep a similar orientation and influence other minor cracks.

In addition to these small disks, we made larger terracotta disks, approximately 16 cm in diameter (see Fig. 4A-B for an example). These disks were made from clay slabs and were surface-manipulated freely by engraving the clay. They were fired to high temperature and glazed with our crackle glaze.

In the example in Fig. 4, we engraved deep horizontal lines surrounded by wide, shallow vertical lines. We found that the cracks followed the crest lines of the pattern, and the larger crackles appeared in the middle of the pattern, where the deep engravings were done.

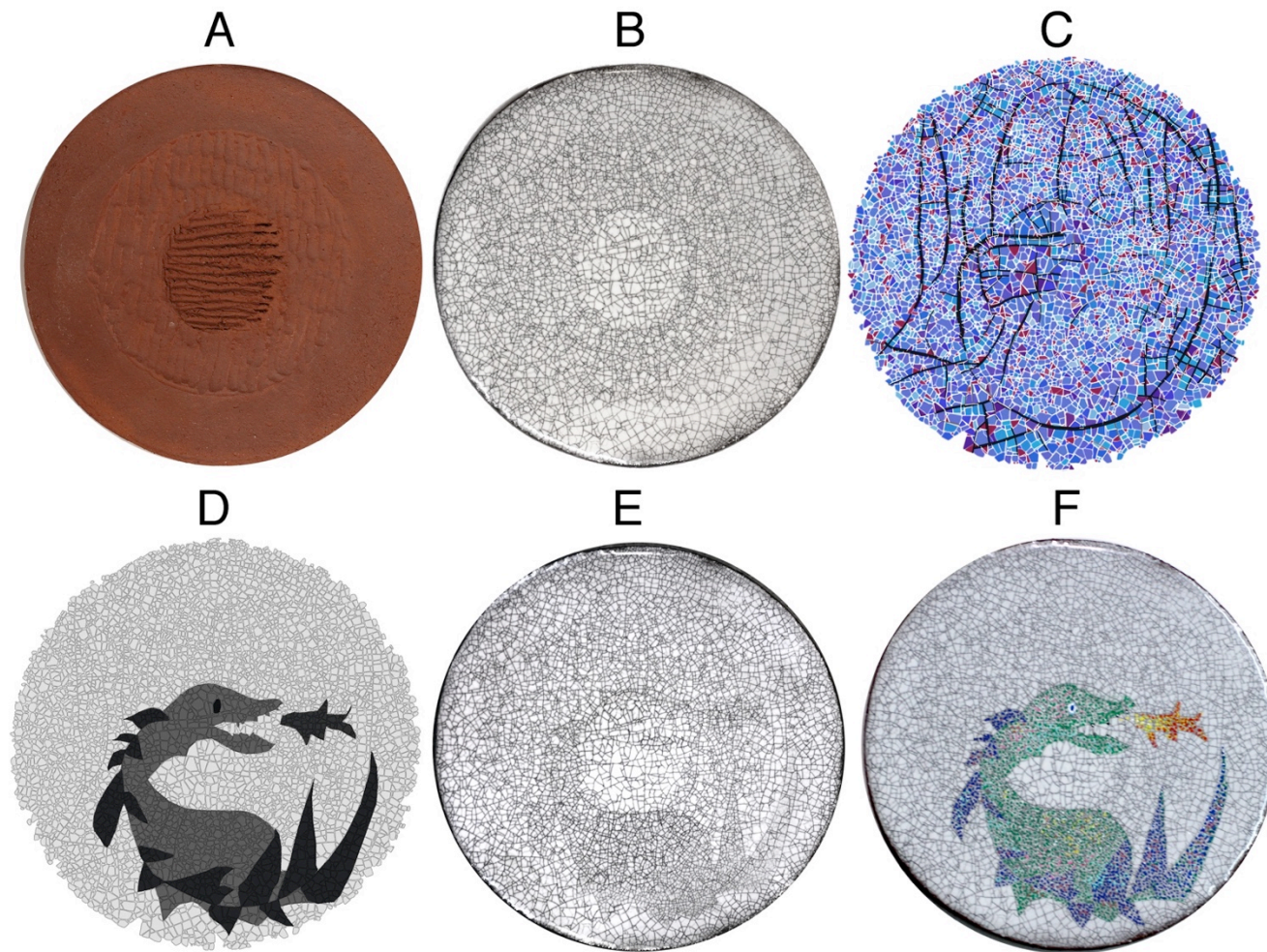
#### *Laser-Induced Crackle by Selective Heating: Crackle Post-Processing*

While crackle appears to result from a tension between the glaze and ceramic surfaces, the tension may not be completely resolved while the glaze cools down, and inner stress may still exist over the glazing surface. Thus, if one heats areas of crackle glaze, it may continue to crack until it relaxes fully.

We experimented with various laser settings until we converged on an optimal laser configuration. Overheating may damage to the glaze (making it boil locally, or engraving it), and under-heating will not have any effect. Moreover, the glaze thickness influences the response of the glaze to the laser, as thicker glaze (with lower crackle density) is more difficult to re-crack.

Using a 40W laser cutting machine with a normal lens, we found that 3 percent speed, 5 percent power, and 1000 ppi gives us an optimal result. To affect the crackle over a specific area, we assign a set of one-directional vector lines to cover it—a horizontal grid of lines 1 mm away from each other. The laser passes through those lines and heats the glaze below. A repetition with small shifts (i.e., the laser should not heat the exact same place again) improves crackle resolution. To achieve improved results on thicker crackles (for example, a 3 mm glaze vs. 1 mm glaze), it helps to take the laser up to 2 mm out of focus.





**Figure 4:** Six stages of preparing a decorative ceramic disk based on a crackle glaze pattern using laser-induced selective heating. (A) Preprocessing of clay disk to create horizontal and vertical guiding depressions; (B) glazed and fired plate demonstrating a dense crackle grid; (C) an output image from our computer-aided pattern-detection (CAPD) tool; (D) a design plan based on (C); (E) selective laser-induced heating results in changes of crackle resolution in selected areas; (F) manual painting above the existing shape.

### **Computer-Aided Pattern-Detection**

After discussing two techniques to affect the presence of crackles, we now present an initial tool for highlighting structures in the crackle grid. After the glazed object is ready and crackles have appeared on the surface, the user studies the crackle and can emphasize the gray-scale effect by using the laser to reveal shapes found on the pattern. While *the user can detect or design crackle structures without CAPD* (such as in Fig. 1-2 and Fig. 5), the tool can assist the user in detecting pre-existing structures and shapes, i.e., to design with minimal intervention.

To use our CAPD tool, a user needs to scan the glazed tiles and filter them using Gaussian pyramids. Then the figures are transferred to vector format and imported to Rhino. Manual fixes to the curves will be necessary to precisely represent the real pattern of cracks.

#### *CAPD Implementation and Interface*

We designed the tool in Grasshopper, a parametric plug-in for Rhino, to visualize forms, sizes, and hierarchies of cracks in ceramic tiles (see Fig. 4C). The tool can assist the user by visually marking distinct groups of symmetry (such as marking square crackles in blue and triangular in red) and grid orientation, allowing the user to decide what symbol or pattern will work with the given crackle pattern. A detailed documentation of CAPD including its limitations and the code can be downloaded from the project site [<http://amitz.co/crackle.html>].

### **Design workflow and process**

The creative process for drawing with light and cracks resembles pareidolia, “the tendency to

perceive a specific, often meaningful image in a random or ambiguous visual pattern” [15], such as observing shapes in clouds or grains of sand. People have already suggested harnessing pareidolia to naturally guided artwork, as in Culshaw’s book *An Atom of Meaning: Playing with Pareidolia: Accidental Art for People who Can’t Draw* [5].

Obviously, every design and art process is subject to personal preferences and skills. Here we share the procedure we used through the projects presented in the paper. The creative process starts by designing or selecting the ceramic object. If designers or artists wish to have some control over the orientation or density of the cracks, they can manipulate the clay surface prior to first firing (see Fig. 4A-B). After the object is fired and glazed, the maker can scan and process the crackle maps using CAPD. Here, the user can fine-tune the outputs to result in several different representations, waiting for a meaningful pareidolia figure or pattern to appear in her or his mind.

In the following step, the user creates a vector file with scanning lines as described previously. For better grey-scale resolution, he or she can use multiple laser passes. After the laser process is finished, the user colors the new crackle with ink as described earlier.

In Fig. 4, 5 we present various work that shows an additional creative stage, where the designer is invited to continue the process and paint over the pattern using acrylic markers. Where a 3D object is used (such as in Fig. 5 and 6), the laser-executing file can be divided into several files with different focal points.



**Figure 5:** A portfolio of three crackle plates decorated with laser-induced crackle and acrylic markers.





**Figure 6:** One of the plates from Fig. 5 before and after laser-induced heating results in changes of crackle density in some areas.

## Conclusions

We present a hybrid design process exploiting naturally produced patterns (ceramic glazing crackle) to make hybrid decoration designs on ceramic objects. We contribute a new technique to impact the density and orientation of crackle using ceramic surface pre-processing, and additional techniques to laser-induce dense crackle pattern by selective heating. Together, these techniques allow for some control over the crackle formation. Using semi-controlled crackle patterns, we rely on deviations in crackle density to express gray scale illumination levels. Putting it simply, as the crackle gets denser, its color seems darker. This enables the user to draw a pattern or structure inside the glaze based on its naturally appearing crackle grid.

In addition, we presented an optional digital design tool, which creates various figures that assist designers in detecting hidden visual meanings in the crackle. The design process itself is subjective and resembles pareidolia, as people rely on their imagination to find meaningful visual elements in the observed field. Then, a laser is used to highlight these elements. If the designer has a preliminary visual intention beforehand, she or he can pre-process the ceramic to help the crackles converge into the required distribution.

We hope this work will inspire more research on hybrid design processes in which human makers integrate naturally generated shapes into their practice. In future work, we plan to conduct more work on computer-aided pareidolia, including a user study, envisioning interactive procedures that can assist designers in detecting and utilizing potential natural structures.



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