Quasicrystalline Ceramics

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Abstract

The emerging digital and fabrication technologies are transforming the way in which material culture is conceived and crafted. Most notably, ceramic 3D printing technologies offer new paradigms for creative exploration and research, enabling the fabrication of complex shapes that are extremely challenging to achieve using traditional methods. This paper designs and tests the fabrication of ceramic jewelry with complex perforated shapes. Specifically, it utilizes a new structural approach to derive design variations with icosahedral quasicrystalline geometry. The new approach provides a direct three-dimensional visual representation of icosahedral quasicrystals, enabling the use of different fabrication strategies and eliminating a major roadblock for researchers especially in the artistic fields. It is worth noting that this approach was originally written for an audience of chemists and physicists and later adapted to make jewelry.

Background

The discovery of Quasicrystals in 1984 [1] shocked the scientific community with the introduction of a new state of matter with "forbidden" symmetry, which was considered impossible to exist for crystalline matter in the traditional definition of crystallography. This puzzling new atomic structure exhibits long-range orientational order but with no translational symmetry. Today, hundreds of these systems have been realized, challenging mathematicians and physicists to unlock their complicated structures. Since their inception, scientists relied on abstract and higher dimensional mathematics to construct and analyze these formations, which often involve mathematical structures beyond our 3D visual system. In 2019, Ajlouni proposed a new mathematical approach which operates within the real physical (Euclidean) space [2]. This approach focuses on the special case of icosahedral quasicrystals, which represents the majority (80%) of all known quasicrystals [3]. The new approach provides a direct three-dimensional visual representation of icosahedral quasicrystals, enabling the use of different design and fabrication strategies and eliminating a major roadblock for researchers especially in the artistic fields. Based on this new method, this paper presents a methodology for the design and fabrication of ceramic jewelry with icosahedral quasicrystalline symmetry.

Deriving the 3D Design Variations

Using the approach described in reference [2], it is possible to derive many design variations of the icosahedral quasicrystalline structure. While the approach allows the construction of complicated structures (Figure 1), this paper focuses on simple design variations, which can also be constructed by combining two 3D tiles (acute rhombohedron and obtuse rhombohedron) as shown in Figure 2. The two tiles have six congruent rhombic faces of equal edge lengths and with an angle amount to 63.44 degrees [4]. This research uses the Rhinoceros 3D software application to construct the different line variations (Figure 3 top). To render line thicknesses, multiple approaches were tested. The first approach uses a pipe function available in Rhinoceros 3D to give a pipe appearance to the final design (Figure 3 middle). A more artistic design choice is achieved by utilizing T-Splines application, a plug-in for Rhinoceros 3D, to add variation of thicknesses to the lines (Figure 3 bottom). The variations of line thickness can be manipulated to achieve different artistic effects and in this case, add a subtle organic character to the structure. This process can also be used to create thicker joints for more structural stability for the printed pieces.

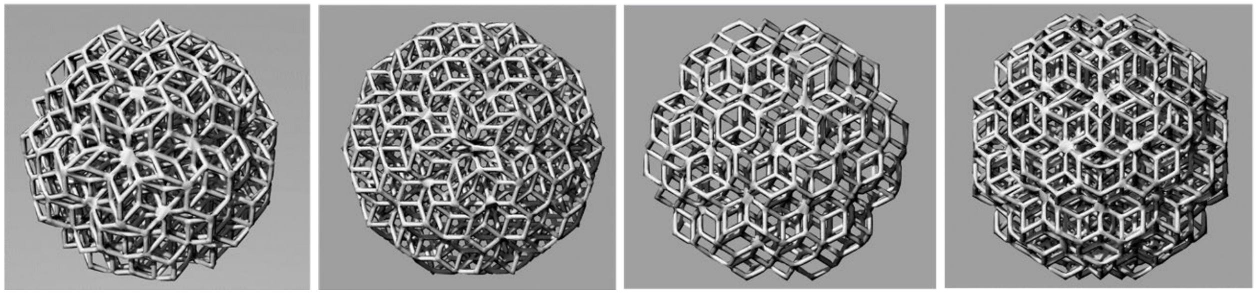


Figure 1: *Complicated design variations of the icosahedral quasicrystalline structure derived from the approach described in reference [2].*

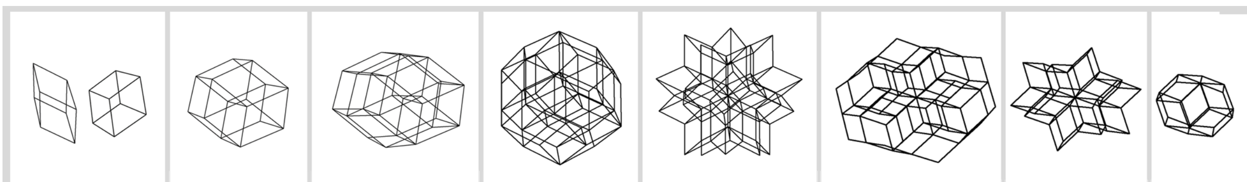


Figure 2: *Simple design variations that can be constructed by combining two 3D tiles (acute rhombohedron and obtuse rhombohedron).*

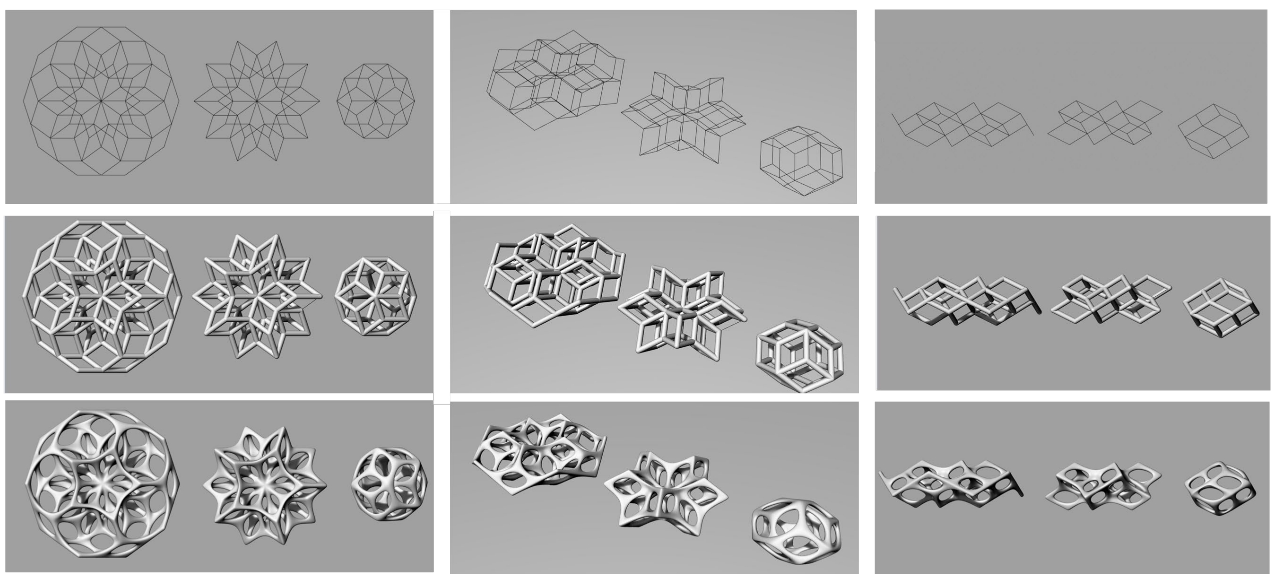
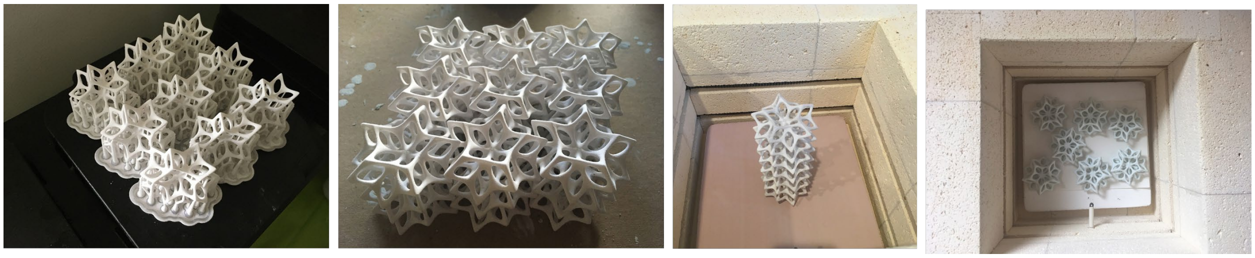


Figure 3: *Some discrete formations selected from the icosahedral quasicrystalline structure. (top) line render, (middle) pipe render using Rhinoceros 3D, (bottom) organic render using T-Splines application.*

Ceramic Fabrication

The fabrication of intricate and complicated ceramic pieces is achievable by combining traditional ceramic crafts with the new ceramic 3D printing technologies. Based on a survey of different 3D printing technologies and due to the delicate and complex nature of the icosahedral geometry, I decided to explore the use of a desktop stereolithography (SLA) system from Formlabs [5, 6]. This printer uses an experimental composite ceramic resin engineered by Formlabs. The ceramic resin is a silica-filled photopolymer, which results in true porcelain ceramic parts after burning the photopolymer matrix in the kiln. The initial 3D printing experimentations revealed a delicate balance between the structure of the design and the different parameters associated with the 3D printing using the ceramic resin. These include orientation of the pieces, scale, membrane thickness, and support structure. Figure 4a shows one successful experimentation with printing multiple pieces of a rhombic hexecontahedron. The next step involves cleaning the support structure and smoothing the printed pieces using different grit sandpaper (Figure 4b).



(a) (b) (c) (d)

Figure 4: *Ceramic fabrication process (a) a 3D printed formation showing the support system used to anchor the pieces while printing (b) a formation after cleaning the 3D printing supports, (c) A stack of pieces after first firing to burn the polymer matrix in the kiln, (d) the second firing to apply the glaze.*

In order to apply glazes to the 3D printed pieces, the firing process includes two different firings. The purpose of the first firing is to burnout the polymer matrix, which requires reaching a temperature of 1900°F, similar to a traditional bisque firing. It is important to point out that, at this temperature, the delicate ceramic particles have not yet fused and are still loosely held together as a powder body and must be handled with care (Figure 4c). This temperature also leaves a porous part that will accept the glaze for the second firing. The bisque pieces are then coated with multiple layers of "high-fire" porcelain glazes and are then fired to 2350°F. Figure 4d shows ceramic pieces coated with blue "high-fire" glazes. It is also possible to apply a permanent gold layer by firing the pieces for a third time. Variations of the resulted glazed porcelain jewelry pieces are shown in Figures 5 and 6.

Figure 5*:* *Color variations of the fired porcelain jewelry pieces (diameter 52mm) [7].*

Figure 6: *Design variations of the fired porcelain jewelry pieces (sizes range between 20mm–62mm)[7].*

Summary and Conclusions

This paper demonstrated the design and fabrication of ceramic jewelry with icosahedral quasicrystalline geometry by using a combination of traditional ceramics and newly available desktop 3D printing technologies. This process enabled the fabrication of complex and perforated shapes that are extremely challenging to achieve using traditional methods. It is important to emphasize that such techniques are still very experimental and currently still in the development phases. The paper utilized a new approach for constructing and modeling the icosahedral quasicrystalline geometry, which provides a direct 3D visual representation of the icosahedral superstructure and enables the use of available fabrication strategies. I hope this approach will help eliminate a major roadblock for researchers especially in the artistic fields.

References

[1] D. Shechtman, I. Blech, D. Gratias and J. W. Cahn. "Metallic phase with long range orientational order and no translation symmetry." *Phys. Rev. Lett*. 53(20) 1984, pp. 951-1954.

[2] R. Ajlouni. "A surface-stacking structural model for icosahedral quasicrystals." *Struct Chem* 30, 2019, pp. 2279–2288. https://www.researchgate.net/publication/335181612_A_surface-stacking_structural_model_for_icosahedral_quasicrystals.

[3] E. Macia, J. M. Dubois and P. A. Thiel. "Ullmann's encyclopedia of industrial chemistry." 2001, Weinheim, Wiley-VCH Verlag.

[4] D. Levine, P.J. Steinhardt. "Quasicrystals. I. Definition and Structure." *Phys. Rev. B* (34) 1986, pp. 596–616

[5] https://formlabs.com/.

[6] https://formlabs.com/materials/ceramics.

[7] R. Ajlouni. House of Geometry, LLC. https://www.etsy.com/shop/HouseOfGeometry?ref=seller-platform-mcnav.