

# Parametric Fabrication for Traditional Ceramics:

## A Dialectical Integration of Traditional and CAD/CAM Methods in Computational Design

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### ABSTRACT

This paper integrates traditional techniques with the parametric approach in ceramic fabrication by outlining several key parameters in both the traditional and digital ceramic fabrication process, and investigating how these parameters can accommodate parametric variation from the digital model. Findings from three experiments with different parameters suggest a promising landscape for traditional ceramic fabrication to be more compatible, not only with the parametric variation in digital modeling, but also with customized digital fabrication.

**KEYWORDS:** ceramics, traditional, fabrication, parametric, shape grammar

### Automated Tradition

Most current manufacturing procedures can be seen as a continuation of traditional production systems. Contour-crafting, press-working, wire-cut EDM, centrifugal casting, extrusion, and many other techniques have evolved from basic traditional ceramic methods such as coil building, extrusion, wire-cut, and wheel-throwing (Fig. 1). In fact, today's use of the router bit and laser in CAM is essentially an automated version of the ancient fire-drill method (Moe, 2010; French, 1997; Peterson, 2000). What has changed, according to Moe, is how the drill is

shifted from being human-controlled to computer-controlled. Furthermore, digital model transformation functions in CAD such as *extrude*, *loft*, and *revolve* also resemble some of these traditional techniques. This ceramic-inspired analogy enables CAD users to model their virtual object more intuitively since memories of various traditional techniques help them to picture how the shape is being physically transformed. For instance, *extruding* polygon is parallel to extruding clay; *lofting* lines is analogous to wire-cut; and *revolving* curve is akin to wheel-throwing in pottery. Thus, in CAD modeling, one can seamlessly elaborate the traditional ceramic techniques.

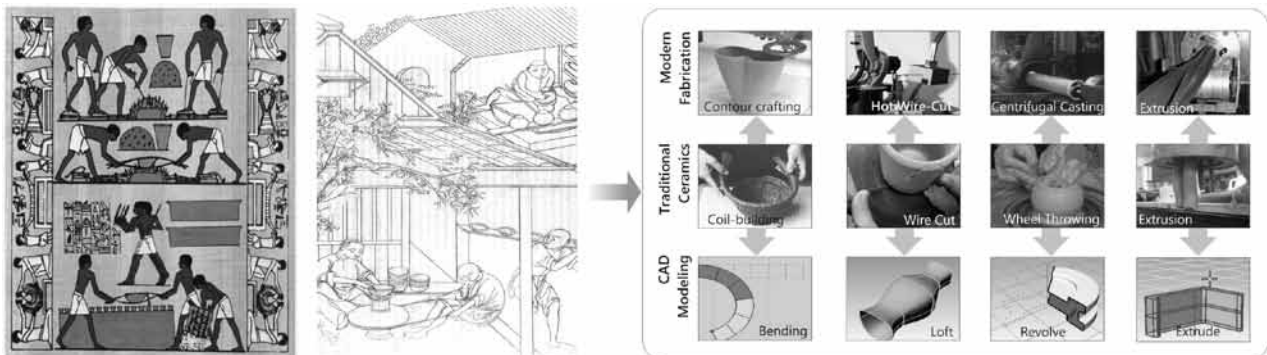


Figure 1. Ancient fabrication adapted in traditional ceramics, CAD, and Modern Fabrication

However, there are serious gaps between traditional and modern ceramic fabrication in CAM. In traditional ceramics, design and fabrication are less distinctive. Because traditional ceramic methods typically require more direct hands-on experience, these methods provide local artisans with immediate physical feedback. They can visually and tactilely sense the surface and constantly revise the design as it is being verified by the material and fabrication constraints in real time (Schön, 1987). This reciprocity is rather difficult to perform in some digital design fabrication because CAD/CAM exchange is a one-way conversation, meaning that the digital model is translated into digital fabrication in a top-down approach. If the fabricated design needs revision, the designer needs to redo the remodeling process and perform yet another top-down CAD/CAM translation. However, a number of recent explorations using robotic controlled fabrication with polyurethane foam show a promising approach for a more intuitive digital ceramics design-fabrication process (Gramazio & Kohler, 2007; McGee and Clifford, 2010).

**Parameterizing Traditional Ceramics**

Despite the evolutionary progression of how the digital manufacturing gained advantages by automating the traditional techniques, our previous discussion revealed a significant discrepancy between what designers might think and what the machine does in CAD/CAM (French, 1997). To minimize this gap, this paper focuses on how traditional fabrication can gain the benefit of computational method. In particular, this research aims to (1) understand the ceramic forming process by outlining the key parameters in both traditional and digital ceramic fabrication process; and (2) investigate how these parameters can accommodate parametric variation from the digital model through a series of experiments.

**Forming Parameters**

Some important parameters to consider in ceramic forming process are the variables for material viscosity, the fabrication process, and the geometrical properties of the tools (Fig. 2). The following parameters are defined conceptually for both traditional and digital fabrication to evaluate their similarities and differences (Tay et al. 2003; Kelkar et al. 2003).

- **Moisture level:** Ceramics fabrication can be parameterized by increasing or reducing the moisture level of the material from 0%- 15% (powder), 15%- 25% (plastic) and above 25% (slip/foam). Specific moisture level generates a special state of clay elasticity in which each state requires a different forming process (Verband der Keramischen Industrie, 2009; Peterson, 2000).
- **Fabrication Process:** (1) *Addition:* New material is added into the existing one (*hand-building or layered manufacturing* in solid free form fabrication); (2) *Deformation:* The material is deformed following mold geometry (*press, casting*

and *extrusion*); (3) *Subtraction:* Parts of the material will have to be removed to obtain the desired shape (*wire-cut or CNC router*) (Schodek & Bechthold, 2005; Kolarevic, 2003; Lefteri, 2007; Todd et al., 1994; Clifford & McGee, 2010).

- **Geometrical Property:** We can geometrically parameterize the additive, deformative and subtractive tools that interact with the material by manipulating the geometry: point (0D), line (1D) and plane (2D). A CNC router bit is basically a point that creates lines in series a number of times; a wire is essentially a line that creates a surface in a series or a set of points in parallel; and an extruder’s die can be seen as a polygon transforming three-dimensional object in serial mode, where positive and negative mold jointly create the same 3D object in parallel.

Together with various transformation methods (rotation, translation and scaling), we can perceive the lattice diagram in Figure 2 as a platform for a procedural exchange between different forming methods.

**Reconfiguring Parametric Ceramic Fabrication**

The Ceramic Forming Lattice diagram shows numerous approaches to set the parameter in ceramic fabrication by varying the combination of different parameters that might lead to various mold/die configurations, either by using a digital fabrication machine or by creating new customizable tools (Fig. 2).

The following experiments explore this combinatory configuration through three digital-analog collaborations with clay (Fig. 2-bottom).

- The first experiment defines the variable for clay with over 25% moisture levels, also known as a slip, using the *deformation* approach. Because slip clay is a highly viscous material, the tool geometry will be implemented in a volumetric mold.

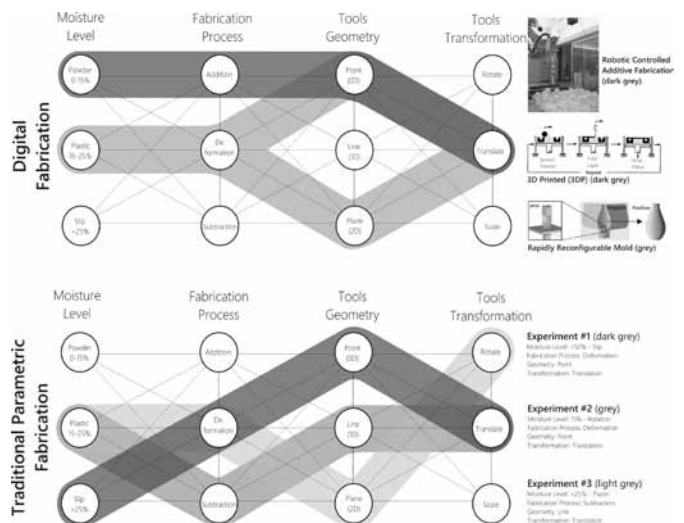


Figure2. Ceramic Forming Diagram: Different trajectories represent different forming methods

- The second experiment uses plastic clay at the moisture level range of 15 to 25%, using *deformation* as the shaping process. With this plasticity, the tools are able to directly manipulate the clay surface.
- The third experiment uses the same clay moisture level as the second experiment: plastic clay. However, instead of using the deformation technique, this experiment uses *subtraction* (material removal) with a line for the tool geometry.

To ensure results that can be compared fairly, all the experiments use the same basic shape, a hexagon, to represent a design and allow the different fabrication approaches to reveal the possible parametric variation.

### Experiment 1: Parametric Casting

The experiment begins by combining a CNC router and traditional slip-casting to bypass the plaster-works. Instead of creating a positive shape and then a negative shape for the mold, here the negative mold is directly fabricated by a three-axis CNC router based on the CAD model as the positive shape. The hexagon variable is defined by the circle radius which intersects the six lines. By changing the circle radius, the hexagon will be parametrically generated in various shapes since a longer radius means a larger hexagon shape, and vice versa. The results of these distinct hexagons are multiplied in one large mold (Fig. 3).

The role of the parametric method in the first experiment mainly occurs in the CAD modeling process, where the design variable can be freely changed to create the desired hexagon variants. However, once the design is physically fabricated with the CNC, it is difficult to parametrically change the parametric variant for the mold.

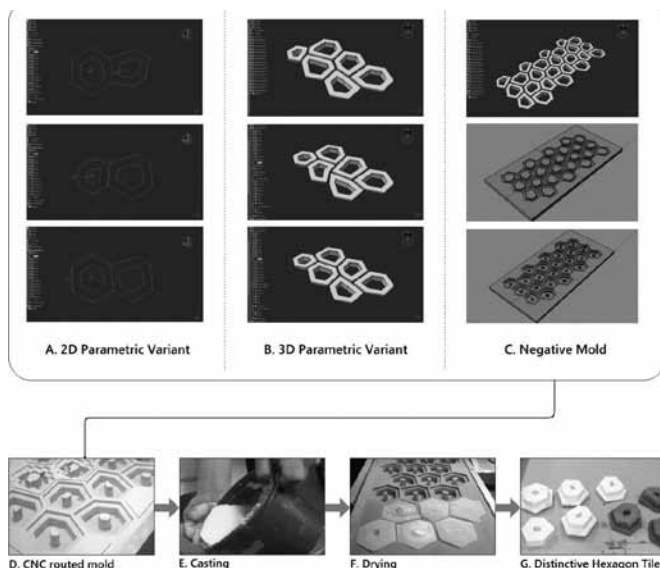


Figure 3. "One-for-All" Slip-Casting Mold (in collaboration with German Aparicio)

### Experiment 2: Ceramic's Aperture

The second experiment mimics the *wheel-throwing* method in traditional ceramics and *wet-press* method from mass-produced ceramic manufacturing, using an analogy of camera *aperture* mechanisms. The diaphragm shutter consists of several leaf-blades that have a rotational degree of freedom to perform parametric variations. The diaphragm opens and closes as the leaf-blade rotates within its center point (the greater the angle, the smaller the opening will be and vice versa). The shutters act as a three-dimensional mold by vertically stacking the shutters on top of one another to form a three-dimensional model. The hexagon variable is defined by the degree of the circle rotation (based on the same center point as the hexagon), which corresponds to the blade rotation. By changing the degree of rotation, the hexagon will be "twisted" from its original shape. The shape of the polygon can be further defined parametrically by changing the degree of leaf blade rotation (Table 1).

To fabricate the design, the first step is to insert clay into the mold cavity. Second, each blade will rotate following the angle prescribed from the digital model. The edge of the blade will press the clay, and together with the other blades, will perform a planar pressure to create a volumetric shape. This method requires a 15-25% moisture level, which is rigid enough to keep the clay body confined inside the mold cavity and elastic enough to be pressed and transformed by the blades.

### Experiment 3: Wire-Cut Grammar

The third experiment investigates using a wire-cut technique as a physical simulation of visual embedding and shape grammar method in computational design.

Whereas the wire is held by the artist at both endpoints in traditional ceramics, in digital manufacturing (hot wire-cut or wire-cut EDM), hand maneuver is replaced by numerically-controlled servo motors while an electric-discharged wire cuts the shapes. In CAD, this process is analogous to *lofting* or *revolving*, where two or more curves act as a guide to resemble the hand and one curve resembles the wire to generate the desired surface. The designer may adjust the parametric variation by (A) changing the height and radius in the digital model or (B) visually embedding and generating different geometries with shape grammar rules (Knight & Stiny, 2001) (Table 2; Fig. 3-top).

In this experiment, the mechanization adapts the above digital manufacturing and traditional wire-cut by digitally defining the curves for the rail and the wire, where clay is manually wired-cut by hand following the guidelines from the curves. The guidelines are laser-cut on two sheets of planar surface based on the three dimensional digital model. The clay is then placed between these two surfaces, wired-cut following the guidelines and the unused part is removed to reveal the desired shape. This method involves only a small contact area (the wire surface) and accordingly, small stress-strain from

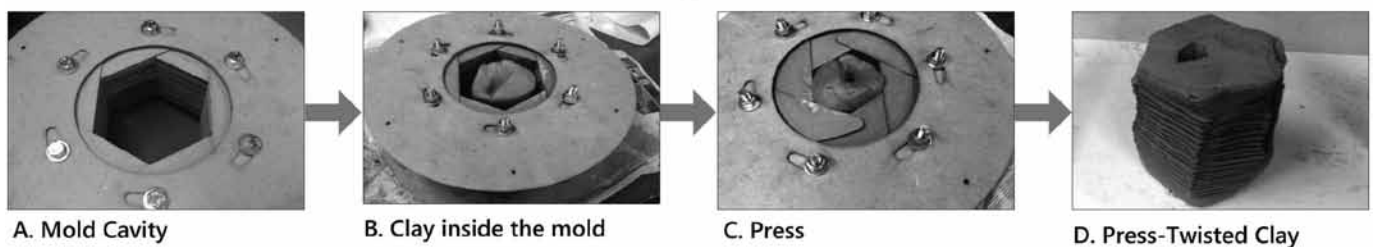
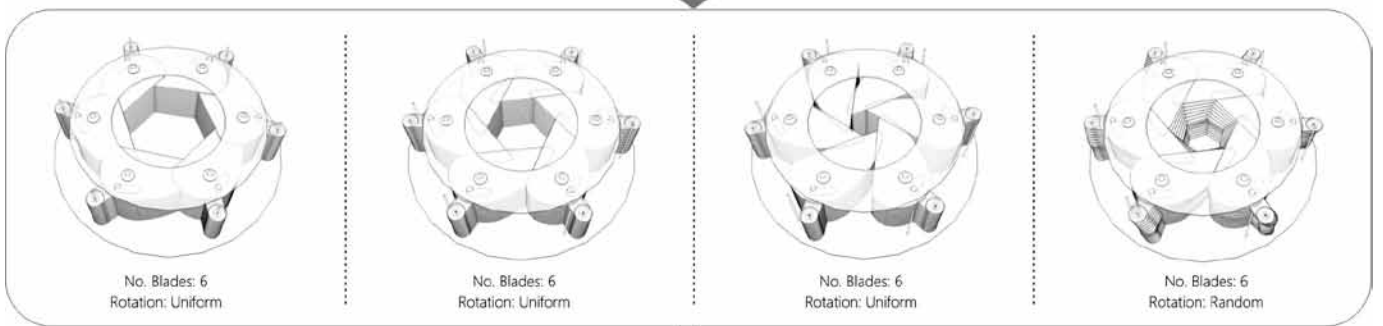
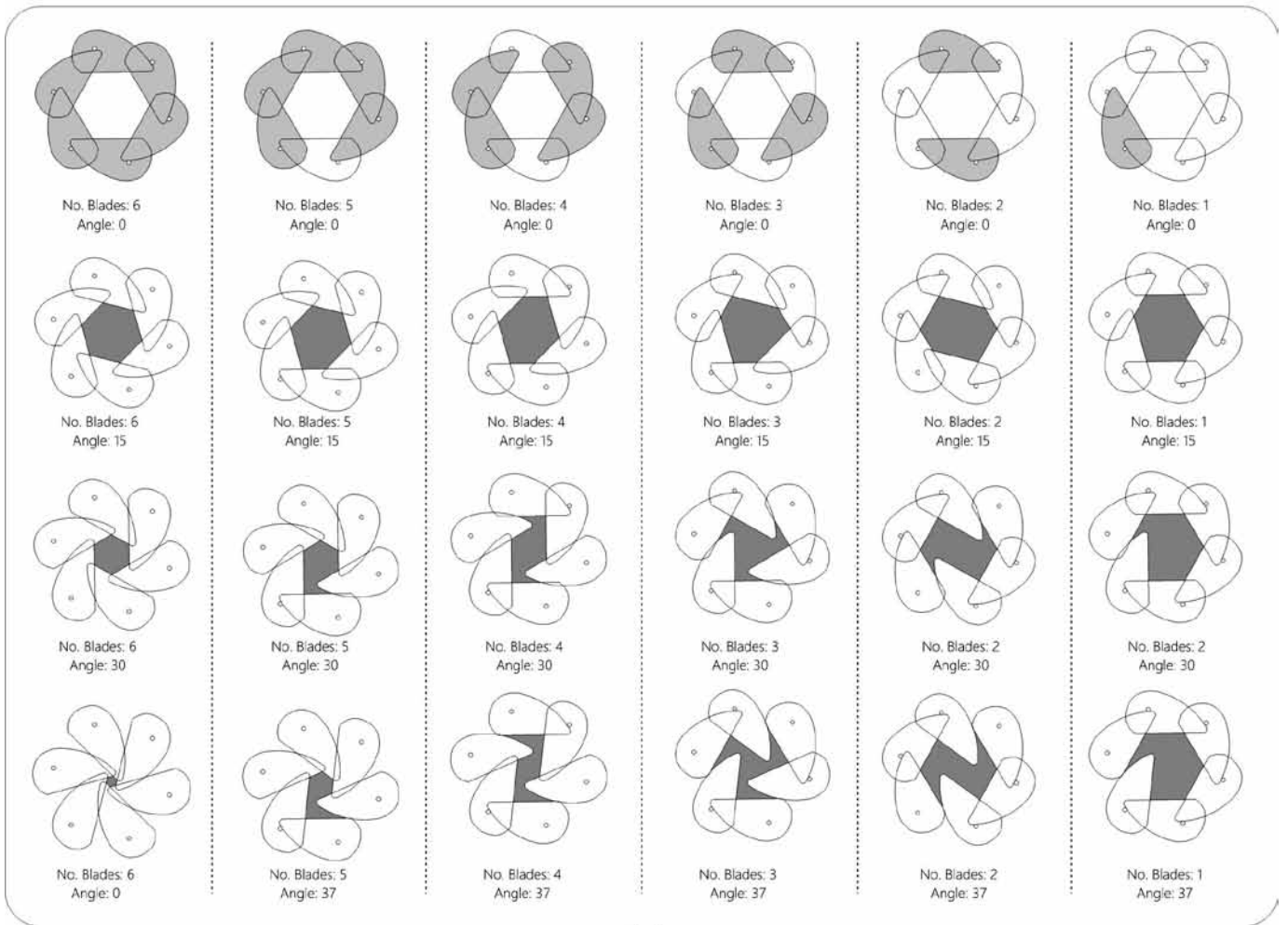


Table 1. Aperture Analogy in combined with wheel-throwing and wet-press methods.



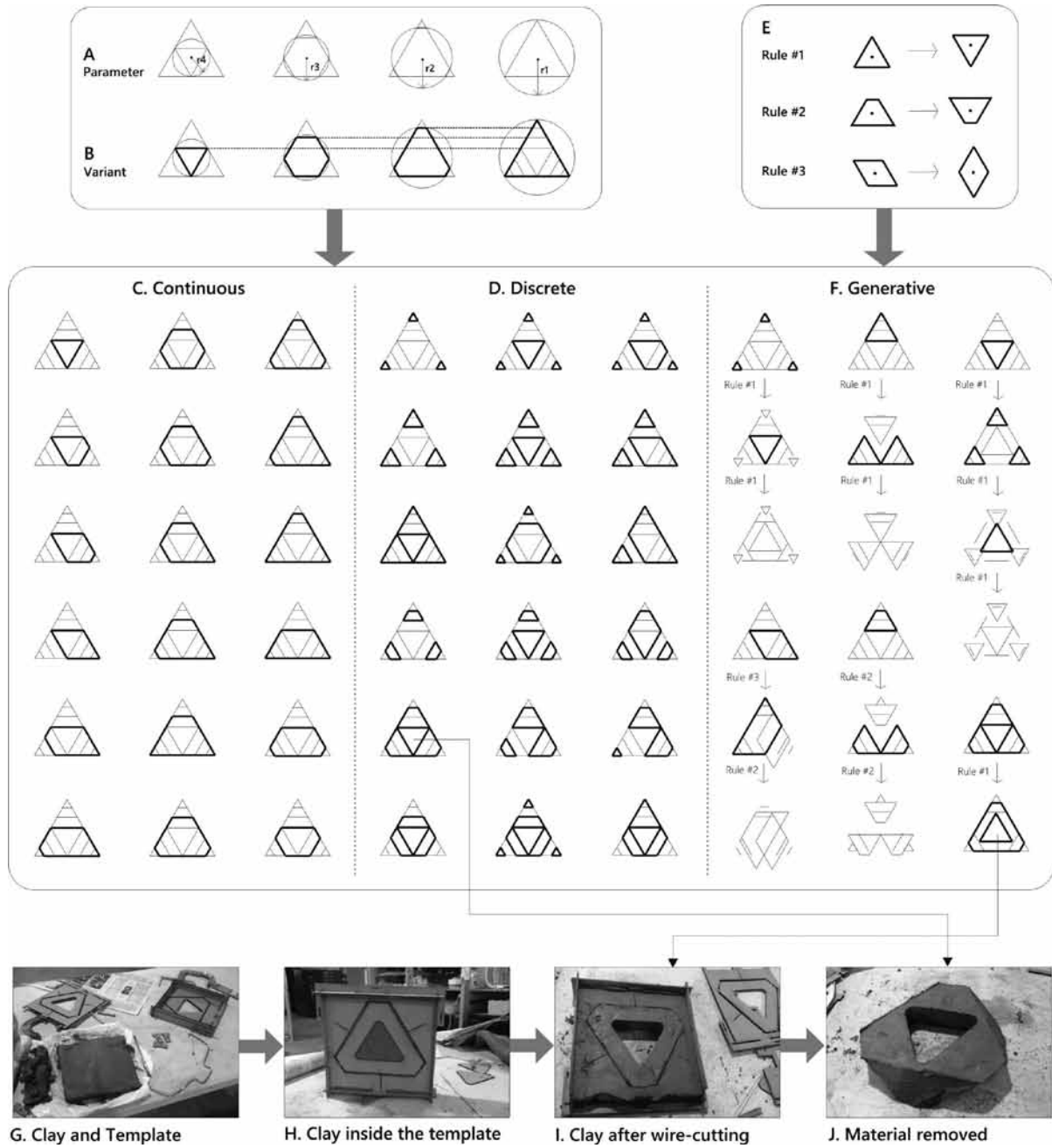


Table 2. Embedding Template and Transformation Rules for Wire-Cut Methods

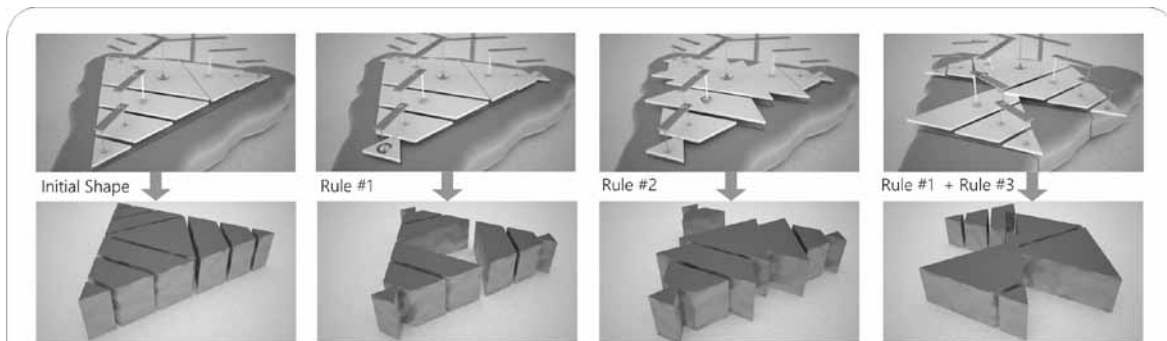


Figure 4. Adjustable Shape Grammar templates prototypes

the clay's surface which resulted in a relatively small required force to cut the clay with a 15-20% moisture level.

## Conclusions

In essence, this research has integrated traditional techniques with a parametric approach in ceramic fabrication by merging the benefits of some amorphous clay, hands-on experience in traditional ceramic and computational methods through the following contributions:

Formulate the apparent gap and feasible correlation between traditional and digital manufacturing in ceramics and outline the geometrical configuration between traditional, digital and analog fabrication.

Reconfigure ceramic forming parameters to provide some possible combinations of different parameters for an alternative parametric fabrication and perform three different parametric fabrications to explore a different ceramic forming configuration.

With these contributions, this study has suggested a promising landscape for traditional ceramic fabrication to be more compatible not only with the parametric variation in digital modeling, but also with customized digital fabrication:

- **Form Follows Fabrication:** These experiments exhibit two consequences: Form follows the fabrication and fabrication follows the form. The first experiments show how CAM enables the designer to generate free-form designs with less constraint regarding the fabrication methods but fewer retrospective features to explore different parametric variation of the initial design. In contrast, the second and the third experiments reconfigure the current CAM configuration to follow a predefined shape and create more constraints to accommodate various parametric variations of the initial design.
- **Physical-Digital Simulation:** The second and third experiments attempt to minimize the gap between CAD functions and CAM methods by reconfiguring the fabrication devices based on the digital transformation methods. The twisting and lofting methods in CAD were using the same procedure as in the fabrication stage, in which the designer can immediately learn the physical result of the virtual model.
- **Crafted Fabrication:** The notion of parametric fabrication in this research does not mean a mere generation of parametric designs, but the tools themselves can also be parametrically assembled (Fig. 4). The second experiment shows the use of analogy from other mechanical system while the third experiment explores the versatility of visual embedding and shape-grammar. This computational aid makes the traditional approach not only closer to the current CAD/CAM benefits in terms of providing parametric design precisely, but also more affordable for the indigenous community.

## Acknowledgement

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