# Shape Cast: Automating 3D Design for Plaster Molds in Ceramic Slip Casting

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## ABSTRACT

Shape Cast is our novel software tool designed to simplify the creation of plaster molds for ceramic slip casting by automating the 3D modeling process. Instead of needing to learn 3D computer-aided design (CAD) to produce molds, Shape Cast allows artists to input a single 2D profile of the desired pot. Shape Cast uses that to generate ready-to-print 3D models for plaster, accommodating factors such as clay shrinkage and mold structural requirements. We detail the mold generation process and associated software capabilities; and, we provide case studies demonstrating the capabilities of Shape Cast.

## CCS CONCEPTS

• **Human-centered computing → Interactive systems and tools**.

## KEYWORDS

Slip casting, 3D design, 3D printing, ceramics, pottery

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## 1 INTRODUCTION

In the realm of ceramic slip casting, artists rely on plaster molds to create their pieces (Figure 1). The process of creating the plaster molds requires a distinct set of skills from those of working with clay. With the rise of consumer grade 3D printers, new opportunities have opened, enabling some artists to design their forms digitally and incorporate 3D printing in their process. While 3D printers have become increasingly user-friendly and reliable, Computer-Aided Design (CAD) software still takes considerable learning to achieve proficiency. Furthermore, many ceramics artists have spent significant time and focused on the physical mediums of their art (clay and plaster) and switching to a digital domain could be perceived as a large change. However, is 3D modeling really necessary to design plaster slip casting molds? As we will show for some forms, the answer is no. The models needed can be very formulaic and thus signal an opportunity for automation. In particular, for one part molds of a revolved form, the geometry of the plaster mold can be derived from the 2D profile of the desired pot.

Our software, Shape Cast, automates the generation of the 3D models needed to create a mold for plaster that corresponds to the user's intended pot to be slip cast. It handles the geometric transformations that would otherwise require significant CAD knowledge. It also considers factors such as clay shrinkage and structural requirements for the mold itself. By inputting just a single 2D curve, Shape Cast generates STL files that can be 3D printed to use as a mold for plaster. The end goal of this automation is to significantly reduce the barrier to entry in using 3D printing for plaster mold creation. The hope is it could both lower the barrier to usage (through eliminating 3D modeling itself as well as the larger time cost of learning to 3D model) and allow artists to iterate on their designs more and explore different form profiles easily. In this paper, we focus specifically on the Shape Cast software and associated capabilities provided to the artist.

## 2 RELATED WORK

Our work on a tool to generate the models needed for creating plaster slip casting molds is situated within the research areas of crafting [9, 10], making [15, 22], and digital fabrication [11, 24]. Work spans from knitting [1, 2] and sewing [14] to drawing [25] and painting [21]. It covers both fabrication technologies as well as and associated domain specific tooling. Some work has specifically investigated practices around various facets of ceramics. Ethnographic interviews with six artists were conducted by Rosner *et al.*, uncovering aspects of the materials and process [20]. Moradi *et al.* examined the routines and methods of individuals performing glazing [19].

There are examples in the literature of digital tools being applied to ceramics. Zoran and Buechley explore 3D printing and slip casting in "Hybrid Reassemblage" [26]. The work by Wakkary *et al.* on the "Tilting Bowl" [23] provides an account of utilizing 3D tools and digital fabrication techniques for the slip casting process. They detail the challenges of working with the medium and bringing new kinds of tooling to bear. Dick *et al.* use a hybrid method that embeds decorations in glaze with the aid of CAD software and laser-selective heating [8]. This research has appropriated existing tooling or fabrication approaches for use with ceramics.

There is work using 3D printers to extrude clay that is fired into ceramics [7] or similar materials like 3D printable play-dough [5]. Finding inspiration in the ceramic practice of coil building, "CoilCAM" is computer-aided manufacturing (CAM) software that ceramic artists use to control the deposition of clay from the 3D

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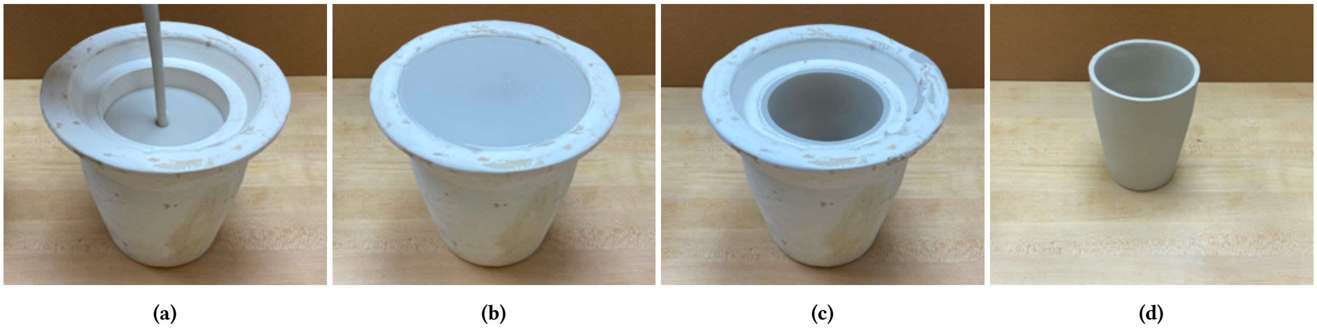


**Figure 1: Slip casting a pot using a plaster mold: (a) Pouring slip into the plaster. (b) Dwell with the plaster absorbing water from the slip, and the pot forms against the plaster wall (c). Excess slip poured out and rim trimmed. (d) Newly formed wet pot removed from mold.**

printer to fabricate ceramic pieces [4]. These pieces either retain the layer lines from printing which is a very specific style, or require post processing of the clay by the artist for more traditional looks. "PotScript" is a tool to parametrically generate ceramic forms that are 3D printed. Given that fabrication approach, it can generate geometry that would be difficult or impossible for slip casting [18]. And other work explores computationally creating flexible molds [3, 16]. However, these works do not take into account the material challenges of plaster molds and clay forms.

Finally, "Slabforge" is a design tool for a particular type of clay work — slab building [12]. This software was born out of the authors' own experience of learning how to use templates for slab building, and the associated effort required to create and modify them. Their software lets the user design a template and provides a 3D visualization of the form. In this way, it is facilitating a mapping between 2D and 3D and serving as a medium for design. As we detail, Shape Cast also spans 2D to 3D, but for a very different type of ceramic making, slip casting.

## 3 PLASTER MOLDS FOR SLIP CASTING

Slip casting involves several components and materials. There are both positives and negatives of a form, and often molds of molds are needed. Here, we provide some background to help ground the reader in the process of slip casting and mold creation to help frame the contributions of Shape Cast. Figure 1 shows the process of slip casting a pot given an existing plaster mold. The artist takes the empty plaster mold, fills it with liquid slip and lets it sit for a period (about 30 minutes for this mold). During this time the water from the slip is absorbed by the plaster, depositing clay on the plaster walls and forming the pot. The excess slip is poured out and the clay in the slip well is trimmed away. Once the pot is sufficiently dry, it is removed from the plaster mold to finish drying. In this paper, we are specifically interested in the process of creating the plaster molds used in this process.

With traditional mold making approaches, the artist creates a version of their desired pot using one of several techniques (made from clay, carved out of plaster, using an existing object, *etc.*). They need to take into specific aspects related to clay such as clay shrinking as it dries and is fired into the final ceramic piece. Also, it is often useful to have a slip well (the top part of the mold in Figure 1). This is a volume that is not part of the final pot where extra slip sits. As the plaster absorbs water from the slip and the level drops, slip stays above the finished rim of the pot. If a slip well is not used, as the level of the slip drops, the thickness of the rim changes (the top is thinner since it has had less time for the clay to build up before the level drops from water absorption). To create the slip will, the original form is modified.

Plaster is poured around this object to create the negative which acts as the reservoir to hold the slip (as in Figure 1). As a result, an outer mold for the plaster is also needed. One common approach is to use cottle boards which are temporary walls to pour plaster into. Once the plaster sets, the form material is removed along with any provisions for the slip well. Martin [17] details this type of mold making and associated slip casting practices.

Shifting into digital fabrication approaches using CAD and 3D printing, the artist would design their ceramic piece in 3D. They again need to account for clay shrinkage and digitally add a slip well to the model. At this point, they could 3D print the form and use traditional approaches to make the plaster mold. However, there are other options available. One is to also model the plaster mold itself. The inner surface is defined by the form of the ceramic piece. With the other surfaces, the artist has discretion since the slip does not come into contact with them and they have only a nuanced influence on the ceramic piece. A naive option is to create a digital cube or cylinder and do a volumetric Boolean subtraction to remove the pot form and create the needed cavity. However, this method uses much more plaster than needed and results in a heavy and unwieldy mold. In practice, other approaches are useful.

The artist can 3D print the plaster form in plastic or resin (a 3D printed version of the plaster in Figure 1). However, this print cannot be used as a mold for slip casting since the absorptive properties of plaster are needed. With the print, they can use two-part silicone or flexible urethane to make a negative of the plaster form — a mold to form the plaster mold. While this is a common approach, some artists are reluctant to use silicone as it is a very expensive material. However, it does have advantages. It picks up the details of the model which eventually transfer into the pot. It is also flexible which is useful since the plaster once set is very rigid. The flexibility of the silicone makes it easier to demold the plaster. Finally, the key benefit is the silicone mold is reusable and the artist can make many copies of a plaster mold for production work.

An alternative to 3D printing a model of the plaster and creating the silicone mold is to design yet another 3D model. In particular, design a mold for the plaster mold which can be printed and liquid plaster poured into. There are some challenges with this approach (the rigidity of the 3D print can make demolding the plaster difficult). However, no silicone is needed and the mold for the plaster is directly created from the print. It is also possible to reuse the 3D print for multiple plaster copies (although likely fewer than silicone). Doing this extra model creation beyond designing the indented ceramic piece can be tedious and effortful with the need to think about several slightly different variations of positive and negative forms and molds of molds of molds. However, with Shape Cast this is all automated and therefore the method we use.

## 4 SHAPE CAST OVERVIEW

First, we describe the input needed for Shape Cast and the associated outputs it provides in relation to the above process. Figures 2 and 3 show an example we created using Shape Cast. The user provides the outer profile of the desired pot as an SVG file. The file contains a single path and is drawn at 1:1 scale of the final desired pot (Figure 2a). This curve represents a slice vertically through the ceramic piece. When it is revolved 360 degrees about the vertical axis at the leftmost point of the profile, the outer wall is formed.

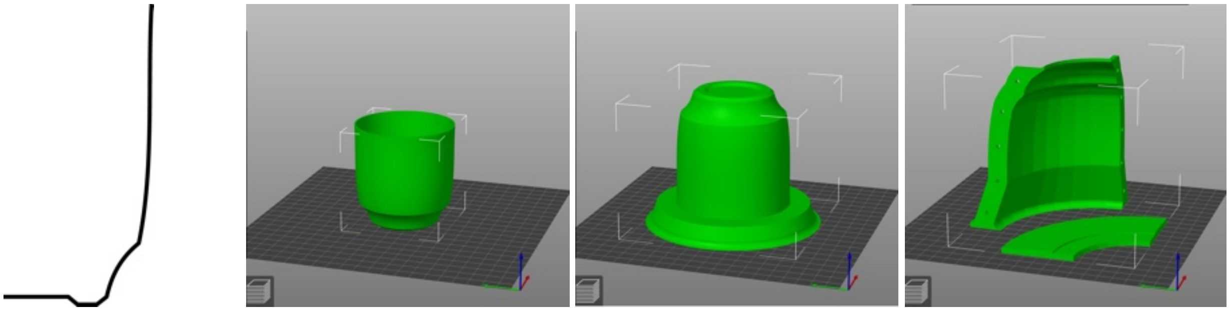
The user uploads this file to the Shape Cast web application which parses it and revolves the profile into a 3D form. This 3D model is rendered for the user and they can interact with the virtual pot by rotating or zooming in and out. This step lets the user check the scale (a grid is provided in millimeters for reference) and get a sense of the form in 3D. If the user is satisfied, they specify their clay shrinkage percentage and select options for the outer mold (described below). At that point, Shape Cast processes the SVG file and creates a design proof STL file (Figure 2b). This is a to-scale representation of the pot that can be printed to verify the form before proceeding onto the more intensive steps involving plaster. In our own usage, this step has been valuable as holding the form often provides insights not offered by the 3D rendering. We have found that scale and proportions are much easier to judge as a physical object (however future work would be needed to verify if this holds for our users).

Next, the artist can either stop and tweak their profile to address any desired changes, re-uploading the new SVG file to Shape Cast, and iterate. Or once content, they can instruct Shape Cast to proceed and it generates all of the 3D models needed to pour a plaster mold. First, it creates the inner mold (Figure 2c shows the model in the 3D printer slicer software). This mold is the form that creates the outer surface of the pot. One thing to note is the parts are printed upside down. There are two reasons for this orientation. One is the outer surface is the critical one, so printing in this direction means there are no artifacts from 3D printed supports. Also, as we only support one piece molds, this orientation is useful for pouring the plaster so any bubbles have a tendency to rise. The form is also scaled up to account for the clay shrinkage selected by the user. For example, the clay shown in the examples in this paper has a shrinkage factor of 13%. Finally, a slip well is automatically added (the bottom most stepped out region). This inner form model is hollow and it is recommended to print with supports when using an FDM printer.

Shape Cast also produces two more types of forms (Figure 2d). These complete the mold needed to contain plaster. The tall form in this figure is the outer mold. The geometry of this part is derived from the inner mold and is offset by about 25mm to create a space for the plaster. It is also split into either two or four parts to form the full circle (here a quadrant is shown). The outer mold is split for two reasons. The first is to account for limited printer build volume. The outer mold is much larger than the target pot. For example, this finished piece has a diameter of 75mm while the outer mold needs to be about 200mm in diameter. By splitting it, molds for larger pots can be created on a given printer bed. The second reason is so the mold can be disassembled to allow for easy plaster removal. In early testing, we tried a one piece outer mold and removing the fully set plaster was extremely difficult. To facilitate assembly and disassembly of the mold, flanges are added and holes for M3 bolts and threaded inserts are automatically placed in the model. Finally, there is a ring to form the bottom of the plaster mold (Figure 2d). This is also printed in parts; however, it can be permanently assembled with cyanoacrylate (CA) glue and also has holes for M3 bolts. The bottom of the inner and outer molds have corresponding holes for threaded inserts. Figure 3, shows these parts printed and how they are assembled.

In addition to generating these STL files, Shape Cast proves some more information. It calculates the estimated volume of the final pot (this is performed at the design proof stage). If the user is targeting a specific volume (such as for a coffee mug), they can use this number to tweak the design. Shape Cast also calculates the volume of the target plaster mold — the void created between the 3D printed mold pieces. This information is provided to the user as well as estimates in weight for the amount of dry plaster and water needed to fill the mold for a specific plaster brand (USG No. 1 Pottery Plaster). In doing so, Shape Cast removes work that would otherwise have been needed to estimate the volume of plaster and the associated calculations for plaster mixing.

Once printed, the mold is prepared for assembly. The threaded inserts are heat set into the 3D print. The pieces need to be sealed so that liquid plaster does not leak. We use neoprene foam tape as a gasket (originally intended for weatherproofing windows) and the models have provisions for this (so it can be compressed and not deform the model). The user may want to improve the surface finish of the inner mold as it is transferred into the plaster, and in turn, the finished pot. The inner mold can be printed with high resolution settings (smaller layer heights and slower speeds). In contrast, the outer mold is only needed to contain the plaster so can be printed on draft settings with no functional impact on the plaster. Additional steps can also be taken to improve the surface finish. Figure 3b shows the inner mold where filler primer was applied in several layers with sanding between coats. The gasket has also been applied. In Figure 3c, the inner mold is attached to the bottom ring and two sections of the outer mold bolted in place. Once fully assembled, plaster is mixed (using the qualities provided by Shape Cast) and poured into the mold (Figure 3d). The hole used to pour in plaster at the top of the outer mold is also automatically generated by Shape Cast. After the plaster is set, the mold is disassembled



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

**Figure 2: (a) is the input profile of the intended form, a small cup. (b) shows the STL file created of the design proof. (c) is the inner mold created by Shape Cast and (d) is the outer mold and bottom ring which are split into quadrants.**

(Fig. 3e). Once it is fully cured and dried, the plaster mold is ready for slip casting (Figure 3f).

## 5 SHAPE CAST IMPLEMENTATION

The key insight enabling Shape Cast is that the geometry needed to create all of these 3D printed parts for these one piece molds can be derived from just the profile of the pot along with some predetermined modifications. For example, the design proof model (Figure 2b) takes the provided profile and revolves by 360 degrees for the outside surface. To make it printable, it needs volume so Shape Cast insets that profile by 1.2mm to create the inner wall of the model. The top is closed off and it is exported as an STL. Here, the 1.2mm is 3 times a nozzle size of 0.4mm (common on FDM printers) to facilitate fast printing.

To generate the other parts, a similar process is used. All of the mold pieces for plaster need to be scaled up to account for clay shrinkage. The slip well is predetermined in Shape Cast and attached to that profile. This curve is the outer wall of the inner mold. The inside wall is offset inward by 2.4mm (this thickness was determined in early testing with the goal of something thin to be fast to print, yet thick enough to be rigid and not let plaster leak). Shape Cast also models the plaster even though it is not printed. This is offset 25mm from the outer wall of the inner mold and also corresponds to the inner face of the outer mold. The outer mold is again offset to the outside by our print thickness to create the needed volume. It is modified by cutting out the top of the mold (the bottom side of the pot) so there is an opening to pour in plaster. The ring profile is also predetermined and anchored by key points on mold. There are some corner cases in the above. For example, a small radius is added to the slip well to round off the plaster and make it nicer to handle. There are also provisions for the flanges and associated holes for bolts and threaded inserts.

In the current implementation, all of this processing is handled by a server. Once the user uploads their profile and confirms it for processing, the SVG path is sent to the backend. The first stage of processing occurs using Inkscape[1] and a custom Python plugin. Inkscape provides a convenient platform for manipulating and creating the 2D paths as described above. One important detail is in computing the offsets needed by Shape Cast. Naive solutions can easily result in misaligned geometry or self-intersecting curves which do not make sense physically. We use a parallel curves algorithm [6] implemented by Clipper [13].

Once the 2D curves are created, the modified SVG file is passed to Blender[2] for the second stage of processing to create the 3D geometry. A separate Python plugin for Blender extracts the relevant paths previously generated. Many of these are revolved by 360 degrees and enclosed to create solid forms. The outer mold and ring are revolved by either 90 degrees or 180 degrees based on the user selection of 4 parts or 2 parts, respectively. Blender functions are used to calculate the volume for the final pot and plaster. Finally, the various STL files are exported and made available through the web app for download.

The front end web app is relatively simple. As mentioned, it allows the user to upload the SVG file and renders a preview. It parses the SVG file to provide feedback to the user about invalid geometry (for example more than one SVG path being present, a discontinuous path, *etc.*). A separate page has provisions for approving the design proof and provides links to the STL files created by Shape Cast.

## 6 CASE STUDIES AND INITIAL USAGE

We created a series of case studies to demonstrate the capabilities of Shape Cast. Each study focuses on different forms, showcasing the versatility and effectiveness in our automated creation of 3D printed parts for plaster molds. The first case study is a small cup with almost straight walls and a scalloped tapering foot (Figure 2) and is the example used above to discuss the features of Shape Cast. The mold in Figure 1 was also created using Shape Cast. The form is tall and features a side wall at two angles. We also explore three pieces sharing a cohesive design language: a large tumbler, a small bowl, and a large bowl (Figure 4). These forms maintain consistent features such as the foot design and the subtle curve of the outer wall, varying only in relative proportions. This set was created by modifying the original tumbler's SVG file. To maintain the same foot and associated profile, the bowls are not just scaled versions, but instead the Bézier control points were manually altered to create the desired profiles (Figure 4a). Here, we only show the inner molds for each form (Figure 4b); however, corresponding outer molds were

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[1] https://inkscape.org

[2] https://blender.org

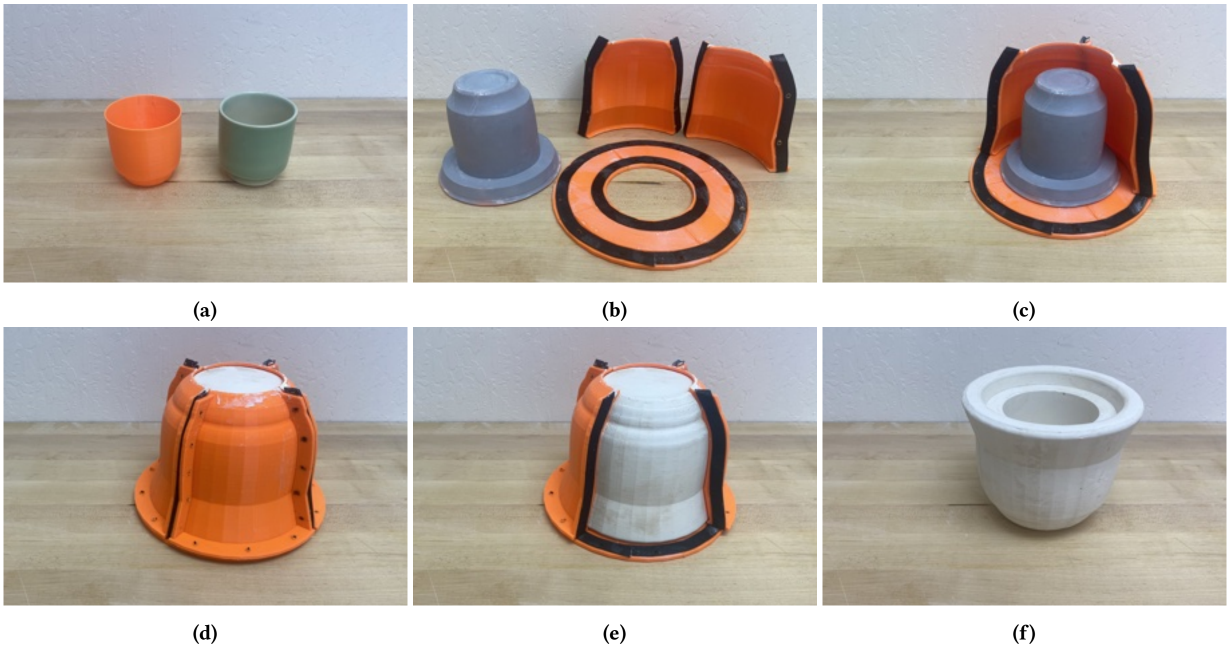

**(a)** **(b)** **(c)** **(d)** **(e)** **(f)**

**Figure 3: (a) the design proof and associated finished ceramics piece. (b) the mold components with gasket applied and inner mold smoothed with primer. (c) mold partially assembled. (d) plaster poured into mold. (e) mold being disassembled from cured plaster. (f) final plaster slip casting mold.**

also generated by Shape Cast and used. Those created the outer walls of the plaster molds for each form (Figure 4c). An example of the final fired ceramic piece of each form is shown in Figure 4d glazed in cobalt blue.

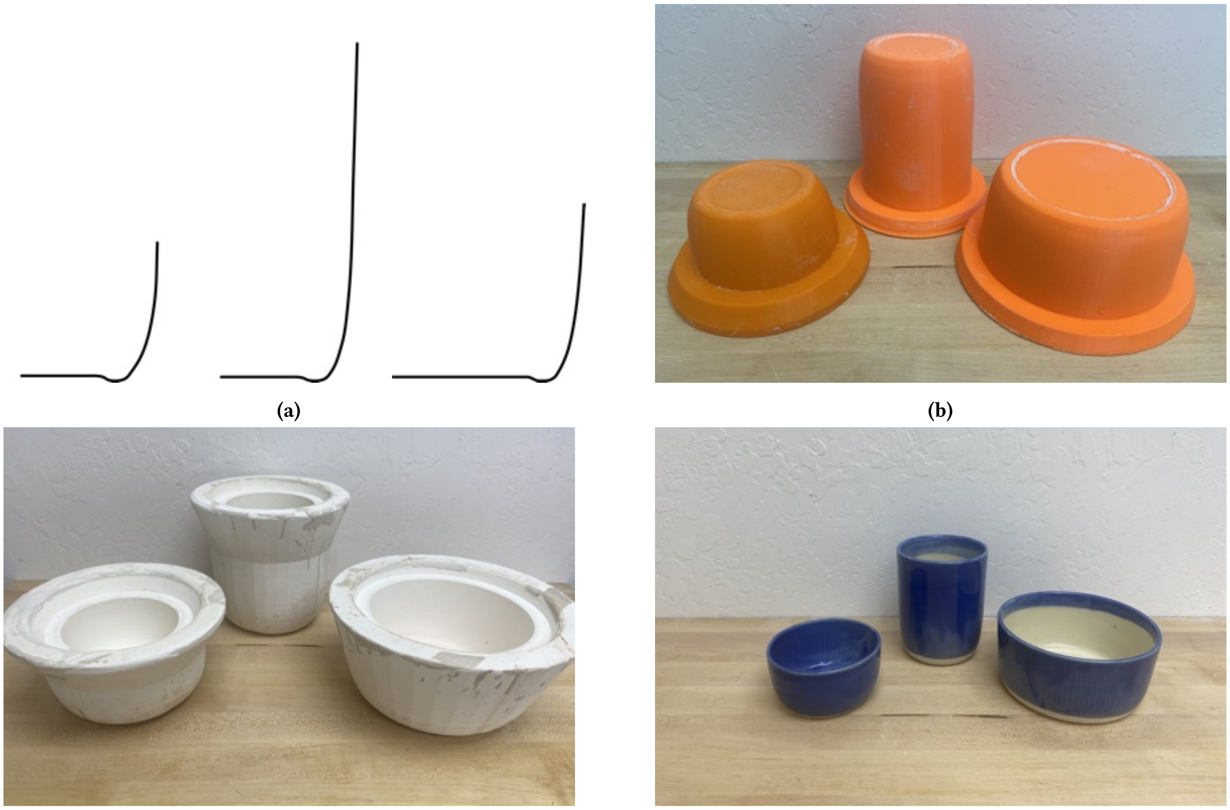
In addition to our own explorations, we opened a beta version of Shape Cast to the public for use. It became available in the Fall of 2023 and at the time of writing, 166 people have signed up. 1,54e SVG design profiles have been uploaded to Shape Cast and 290 fully finalized 3D plaster mold designs were created. We have not examined this early usage, but it proved very useful during development for finding many corner cases not correctly handled with the geometric processing. Informally, we have seen a lot of variation in the designs being created despite the limitation of only creating one piece molds.

## 7 FUTURE WORK AND DISCUSSION

There are several areas to explore with Shape Cast. One is to continue to increase the capabilities of the software. Right now it is limited to one part molds, but we have created some proof of concept two part molds with slight modifications to the processing pipeline. We would also like to explore non-revolved forms. The current infrastructure should support extruding the profile along an arbitrary closed path instead of just in a circle. These could be provided shapes such as regular polygons, or potentially we might allow for an arbitrary second profile. We could also extend into multipart plaster molds which are needed for some forms. As we move into more complex forms, we need to consider not only the generation of the pot form, but the functionality of the plaster and requirements for the 3D printed parts to be assembled and disassembled resulting in a functional slip casting mold as we do with our current one part mold system.

There is a lot of work that could go into better error handling for the SVG file. In our early public usage, we received many files that did not work properly and gradually iterated on detecting the issues. However in many cases, the input SVG provided was invalid in some way. Some of the harder cases are where the SVG looks correct to the user, yet the underlying data structure in the SVG does not adhere to our requirements. For example, there were examples where the line width of a path obscured self intersections or discontinuities in the line. More generally, while we have removed the need for 3D CAD modeling, in its place we have a 2D CAD situation. The SVG data is providing instructions to the software on how to draw the needed curve. This creation process is likely much simpler than 3D, but the mismatch between a design that looks right versus one that properly specifies the curve is an area to investigate.

And finally, we would like to perform user evaluations. It would be interesting to understand how people are using Shape Cast. For example, how is it fitting into their workflow? Prior work has shown side-effects with introducing design tools in ceramics [12] and understanding possible trades-offs the artists face in changing practice would be worth exploring. We found the design proof stage useful in our own testing, but this would also be good to confirm with users. Similarly, there might be other ways to bridge the digital and physical worlds to better understand forms. We also want to collect data to test if we are lowering the barrier for usage and allowing more iterations on designs with Shape Cast as we intend.



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

**Figure 4: A case study of three forms sharing a design language. (a) are the input profiles and (a) are the corresponding inner molds generated by Shape Cast. (c) shows the finished plaster slip casting molds and (d) shows examples of each finished pot.**

## 8 CONCLUSION

Shape Cast is our approach for leveraging the power of digital fabrication for slip casting by focusing on automating the mold design process. This tool simplifies the creation of 3D models for plaster molds by requiring only a 2D curve as input, thus removing the necessity for 3D CAD skills. Its development reflects on careful consideration of the needs inherent in creating plaster molds. It handles all of the geometry manipulations needed to create STL files. After being printed and assembled, the artist can directly pour plaster to create their molds. Future enhancements of Shape Cast could offer more capabilities to explore more complex forms. The integration of digital tools in traditional crafts like ceramics will likely continue to evolve practices and offer new possibilities for artistic expression.

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