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Demonstrating a new approach for personal and digital fabrication of moulded pulp products

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In this paper, we demonstrate an approach for designing 3D printed porous moulds, which can be used by individual to create moulded pulp objects of desired form. This approach requires user to provide simple partitioning of the 3D digital model for the moulded pulp object, and then apply program scripts on a 3D modeling software to generate elements of a porous mould which can be 3D printed with low-cost desktop 3D printers. Indeed, the entire process (from mould design till production of moulded pulp object) can be done at home or in makerspaces with 3D printers. The significance of this paper is on demonstrating feasibility of small-scale production of moulded pulp objects, without relying on expensive industrial manufacturing facilities as in conventional approach. This opens up the possibility for individual designers to experiment with moulded pulp products, thereby allowing them to get feedback for enhancing their products and possibly scale up their production volume.

Keywords: moulded pulp, digital fabrication, porous mould, 3D printing, parametric design

1 Introduction

Moulded pulp product (MPP) is a general term used to describe product which is made from pulp or fiber through moulding, with egg tray as the most widely known example. According to International Molded Fiber Association (IMFA) (2019), MPPs are being used for food related packaging, industrial or engineering packaging, single medical use and horticultural tray and pots. As MPPs are made from cellulose, they are totally renewable and biodegradable, and demands are increasing due to the sustainable nature of the product. Didone et al (2017) gives a comprehensive review on history, applications, processes, tooling, mechanical properties, and environmental impact of MPPs.

However, existing approaches in manufacturing MPPs involve use of metal moulds and porous materials, vacuuming and intense temperature and pressure with specialized industrial machines (Didonet et al, 2017), which are difficult and expensive for individuals to create MPPs in small quantities. With abundance supply of paper pulps from waste paper around us (including newspaper, books, magazines, office papers, cardboards and even drink cartons), it will be beneficial to have an approach which allows us to produce MPPs without need of accessing these specialized tools and environment. This facilitates individuals in exploring innovative use of waste paper, and encourages their local recycling, thereby promoting sustainable development in cities.

In this paper, we demonstrate a newly developed approach on using 3D printed porous moulds for creating MPPs. This approach requires access to 3D modelling software (Rhino 3D modeller (www.rhino3d.com) in our current study, but can also be other computer-aided design software which supports boundary representation and scripting for parametric design), 3D printers, and conventional tools which can be found in household or makerspaces. The motivation for developing this approach is to enable production of moulded pulp objects through digital fabrication (Gershenfeld, 2012), so that the approach is accessible to individuals without need of specialized tools. This approach is still a work-in-progress, and we expect to report further refinement in coming future.

2 The Approach and Preliminary Results

2.1 Overview of Process and an Example Mould

According to Didone et al (2017), the entire process in manufacturing MPP includes:

1. mixing - mixing paper with water and add additives to prepare pulp with desired consistency
2. forming – shaping pulp by custom designed tools through vacuuming
3. pressing and drying – wet part from step (2) is moved to a heated mould which is then compressed to improve surface smoothness, dimensional accuracy and mechanical strength
4. trimming and quality inspection

Step (3) requires moulds which can tolerate heat (from 100°C to 350°C) as well as pressure (from 3 to 8MPa), and are usually made from metal in production to improve durability. While this step is important in improving smoothness, dimensional accuracy and mechanical strength, facilities for carrying out this step is not easily accessible by individuals.

Our approach follows a similar process, but combines Steps 2 and 3 with the use of 3D printed porous mould which can be fabricated with 3D printers. Figure 1 shows different parts of a 3D printed porous mould, which is used to produce the MPP in Figure 2. The mould consists of three parts, and are put together by bolts-and-nuts so that pulp inside can be compressed while drying, thereby increasing the strength of the resulting MPP.

Figure 3 shows a cross-sectional view illustrating how the three parts of the mould are put together. The red one is the top mould, the purple one is the middle mould and the green one is the bottom mould. Note that the middle mould acts as a “guide” along which protruding part of the top mould moves. The cavity bounded by the three parts of the mould are for filling the pulp, and pressure is exerted onto the pulp by pushing the top mould through tightening the bolt-and-nut on the four corners of the mould. The protruding part is slightly smaller than the “guide” (with a gap size of 0.3mm as shown in Figure 3) to allow it to move along the “guide”, but yet large enough to avoid paper pulp from leaking out while compressing the pulp.

The mould is printed with a low-cost FFF (fused filament fabrication) 3D printer using PLA filament, and each mould consists of holes in three orthogonal axes, with each hole having a radius of 0.8mm. Those holes are for draining water when the pulp is compressed, and for water to evaporate while the pulp inside is drying under pressure. The radius is being selected due to limitation of the 3D printer, as the nozzle size of the printer is at 0.4mm diameter, and holes with radii smaller than 0.8mm cannot be reliably printed. Smaller holes can be achieved with different configurations (e.g. using smaller nozzle size) and printing technologies (e.g. stereolithography and selective laser sintering). For example, we have used a Form 2 3D printer (from FormLabs, formlabs.com) using photo-polymerized resin to achieve a hole size of 0.35mm radius.

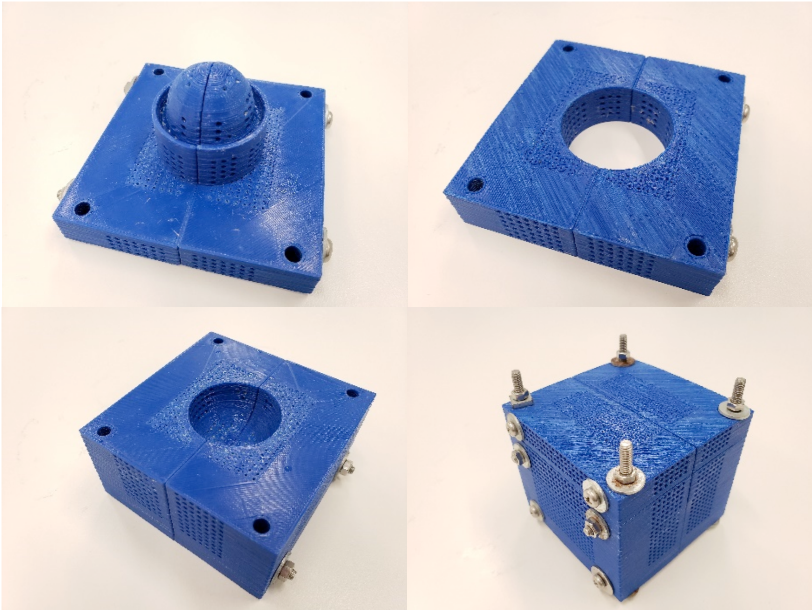

Figure 1: Three parts of the mould: top mould (top-left), middle mould (top-right), bottom mould (bottom-left); the three parts of the mould are put together with bolts and nuts to form the complete mould (bottom-right).

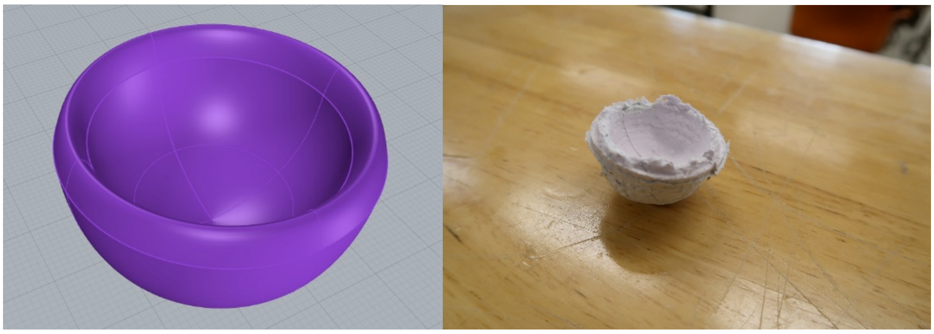

Figure 2: The model (a simple cup) of the moulded pulp object for demonstration of the process (left), and actual object being moulded (right).

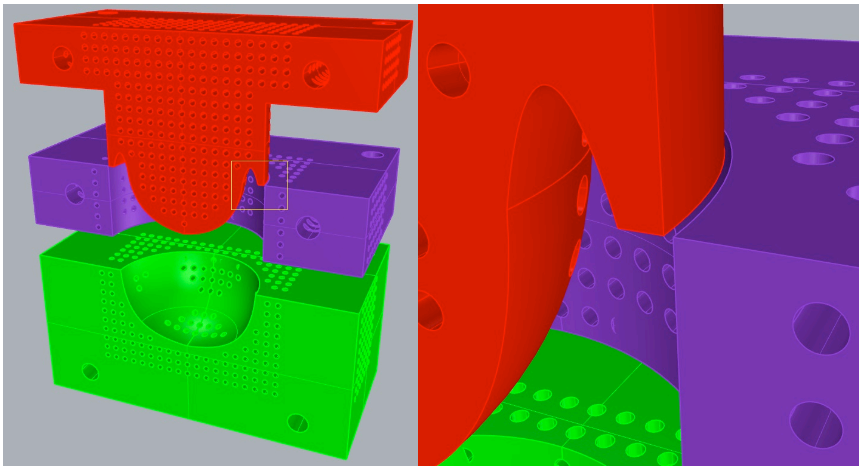

Figure 3: Cross-sectional view of the complete mould, showing how three parts of the mould fit together (left). Zoomed view of the yellow box on the left image shows the gap between the top mould and the middle mould, which measures to 0.3mm (right).

In the section 2.2, we will walk through the detailed steps to create a moulded pulp object with the above 3D printed porous mould. Then in the section 2.3, we will briefly talk about how the mould is being designed through parametric approach.

2.2 Fabricating Moulded Pulp Object with 3D Printed Mould

The following is the detailed steps to create an MPP with a 3D printed porous mould. The steps are as follows:

1. Waste papers and envelopes are teared up into small pieces and mixed with water for preparing pulp (Figure 4). Pound the mixture until they break down into a pulp.

Figure 4: Teared up paper and envelope in water

2. Pour the pulp into the mould (Figure 5). Note that the one on the left consists of the middle and bottom moulds. After pouring the pulp, the top mould is pressed onto the pulp to squeeze out as much water as possible. As water in pulp cannot be drained out entirely by just applying pressure without drying, more pulp have to be added and then squeezed, so as to increase the density of paper fiber in the resulting MPP. Note that the compressed pulp at this phase should have a larger volume than the desired one, which allows for further shrinkage while drying.

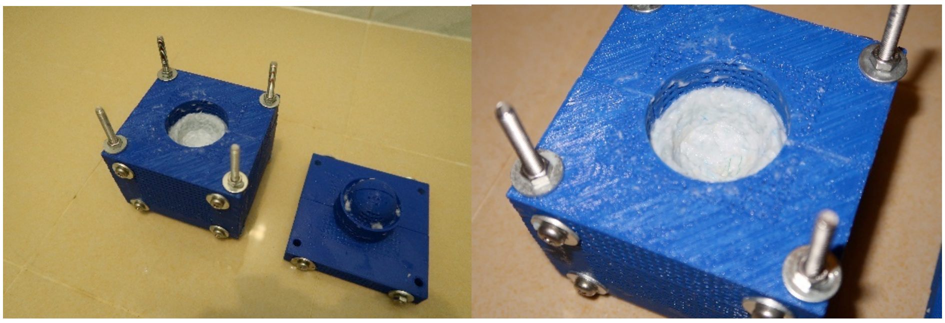

Figure 5: Pulp is poured into the cavity formed by the middle and bottom moulds, and compressed with the top mould (left). Close-up view of the pulp in mould after compressing (right).

3. After putting enough pulp inside the mould, the upper mould is put on top of the lower and middle moulds, and bolt-and-nut on four corners are tightened to maintain pressure on the pulp. The entire pulp is either being dried in open area, or put into a temperature-controlled oven at about 50°C. We called this the "1st phase drying", and the purpose is to allow the pulp to dry up to a reasonable level so that the pulp can be removed from the mould for the "2nd phase drying" in Step 4.

   Drying in open area will take longer time (about 1 or 2 days), but this will not degrade the mould which is printed with PLA. Applying heat to the pulp helps to speed up the drying process, but doing so will degrade the mould. In fact, PLA tends to break down at temperature higher than 60°C (Zhang, et al, 2008), and hence it is not preferred to heat the mould at temperature higher than 60°C. Another concern is the "Heat Deflection Temperature" (HDT), which corresponds to the temperature at which PLA deforms under a specified load. For PLA, HDT is at 49-52°C at 0.46MPa. As the mould is exerting pressure onto the pulp, it is important to use an appropriate temperature to reduce deformation of the mould due to heat. Hence, we set the temperature at 50°C, and keep that for 2 hours.

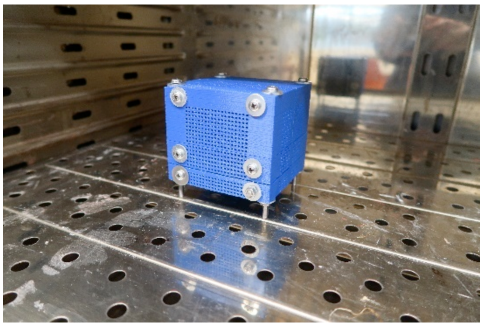

Figure 6: Mould with pulp (while under compression) is heated in temperature-controlled oven at 50C for 2 hours.

4. After the 1st phase drying, the pulp has substantially reduced its water content and easier to hold its own shape, and can be removed from the mould. The mould is designed in such a way that each part can be split up into two halves, so that the pulp (while still wet) can be removed from the mould (Figure 7). Note that the pulp is still wet and can be deformed by exerting pressure onto it.
   The pulp is then gone through the "2nd phase drying" in a temperature-controlled oven at 140°C for 2 hours (Figure 7) to remove excess water from the pulp to arrive at the final MPP.

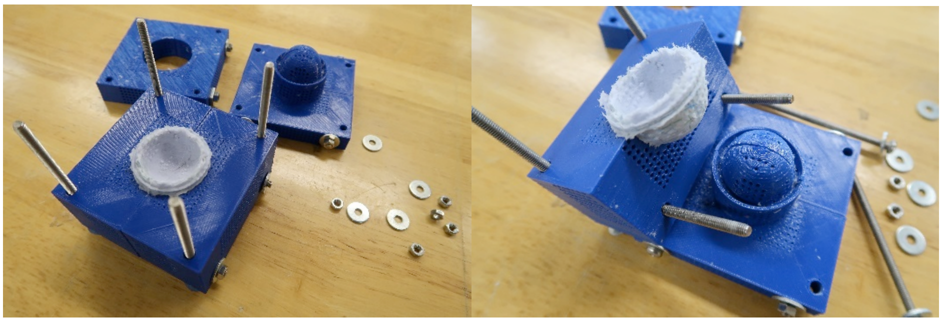

Figure 7: Remove MPP (not entirely dried) from mould after 1st phase drying

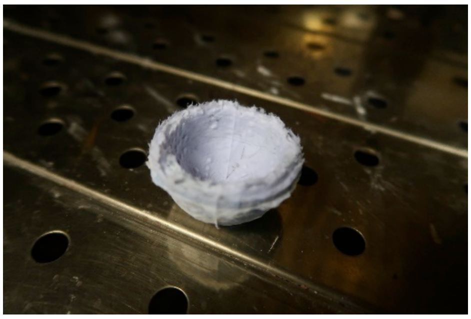

Figure 8: MPP (not entirely dried) is heated in temperature-controlled oven at 140C for 2 hours

2.3 Mould Design through Parametric Approach

Designing an appropriate mould is a very important step in moulded pulp production. In order to simplify the entire process in designing a mould, we developed a number of scripts running on Rhino 3D modeller (www.rhino3d.com) for generating different parts of the mould. The steps in mould design is as follows:

1. Create a 3D model of the object to be moulded. One can refer to Figure 2 as an example.
2. Partition the model into three parts: lower model, upper model and lower negative model. Figure 9 helps to visualize the three parts, based on the one in Figure 2.

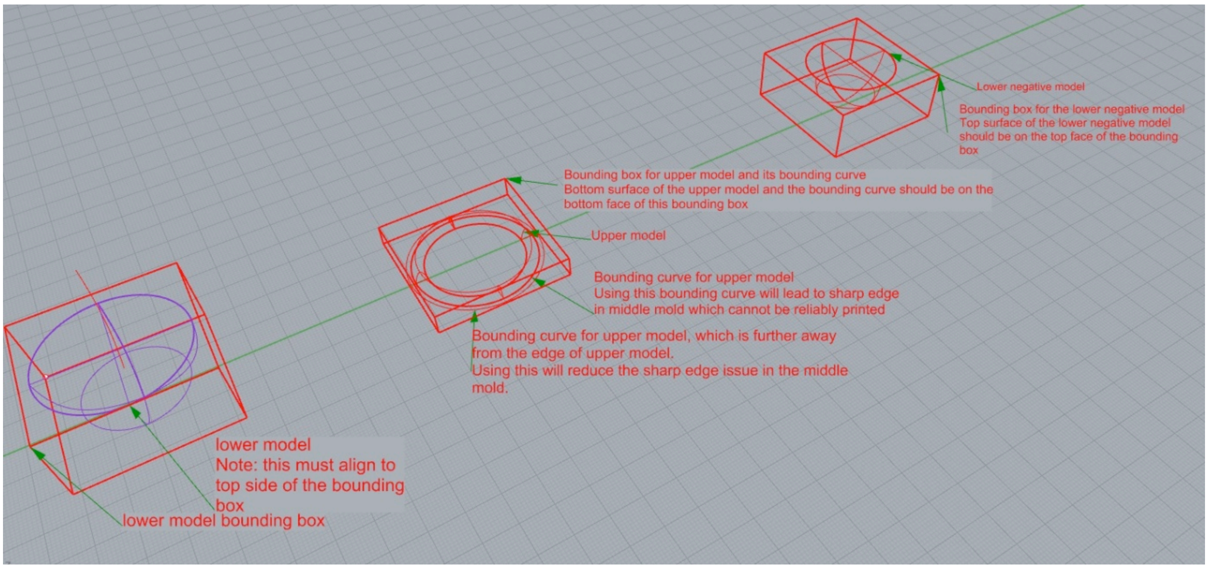

Figure 9: Decomposition of the model of the object to be moulded into three parts: lower model, upper model and lower negative model

3. By using the three partitioned models together with some other geometries as shown in Figure 9 (including bounding curves and volumes of the corresponding 3D models), a script in Grasshopper (a parametric design plugin in Rhino 3D modeller) is executed to generate a number of 3D objects and reference points as shown in Figure 10.

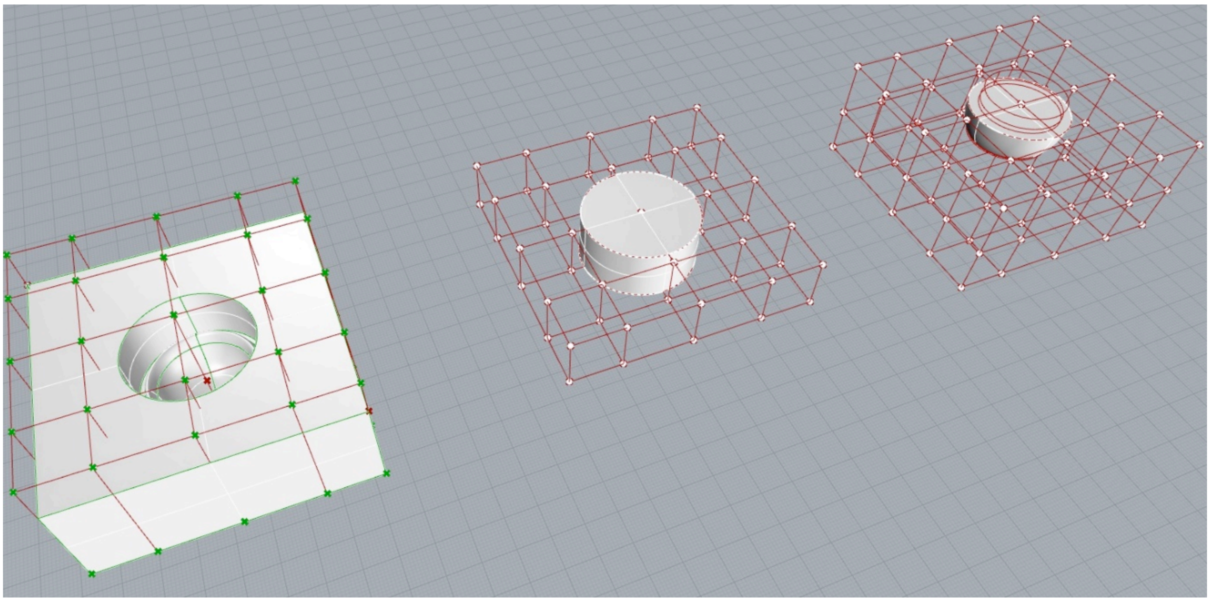

Figure 10: Three sets of objects and reference points generated by a Grasshopper script. These are for generating different parts of the mould, and they correspond to (from left to right) top, middle and bottom mould.

4. Each set of geometries in Figure 10 is used as input to a program written in PythonScript under Rhino 3D modeller to generate holes (cylinders to be exact) along three axes. Figure 11 shows the corresponding part of the mould (half of each mould) being generated. Briefly speaking, the part of the mould being generated is the "negative" of the geometry in the corresponding set of the objects in Figure 10, and then cylinders are removed in the resulting part.

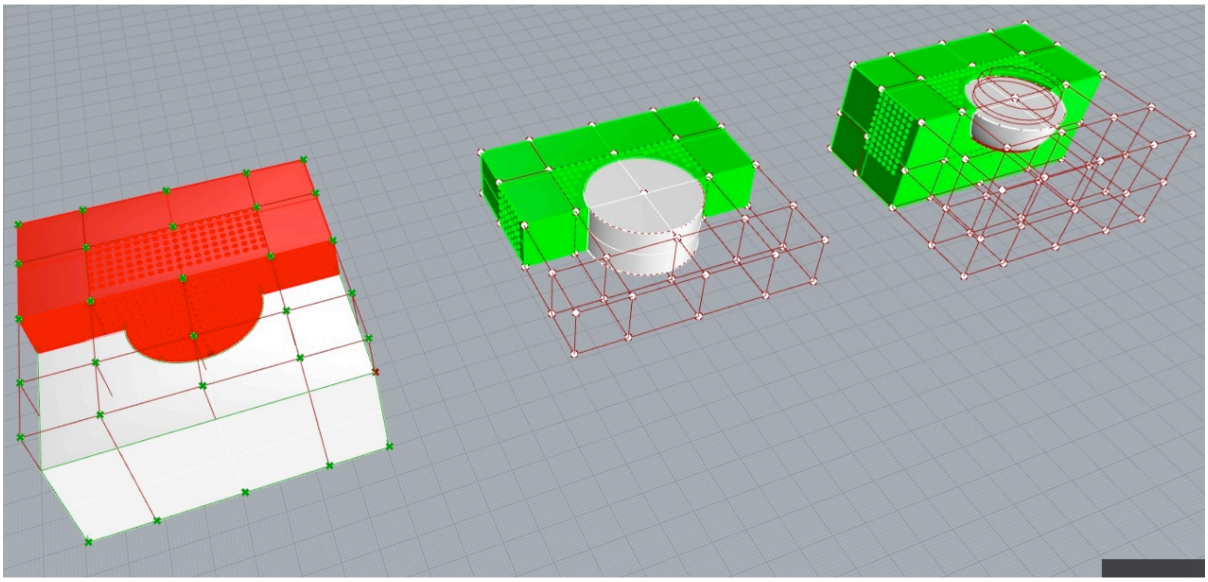

Figure 11: Half of each part of the mould being generated by the PythonScript program in Rhino 3D modeller, based on geometries in Figure 10.

5. Additional holes are then added for inserting bolts for aligning different parts of the mould, and the mould can then be used for fabricating MPPs.

3 Conclusions

This short paper demonstrates a process in creating moulded pulp products using 3D printed porous mould. The entire process requires 3D modelling software and 3D printers, as well as simple household tools like screwdrivers and pliers, and optionally temperature-controlled oven. In fact, the entire process (including mould design, fabrication and moulded pulp products fabrication) can be carried out at home or in makerspaces with simple tools and 3D printers. This allows individuals to manufacture customized MPPs in small quantities, and allow them to explore and evaluate innovative applications of pulps, especially those extracted from waste paper, which are abundant in cities.

We are still in the process of refining our approach, especially on scripts for assisting individuals to create moulds. For example, we are working on a Grasshopper script which allows user to define their parting line of the mould instead of partitioning the mould in a uniform manner. Also, the computational efficiency of the program in PythonScript for generating holes can be improved, so that more holes can be generated. The surface finishing of the moulded pulp object is highly affected by the quality of the moulds, especially on the hole size. In fact, small number of holes lengthens time to dry, and while large hole size leaves visual artifacts on the moulded pulp objects. Hence, it is desirable to have smaller hole size and more holes. In this paper, we reported using PLA for 3D printed porous mould with a hole radius of 0.8mm, which can still be fabricated by using FFF 3D printer with smaller nozzle size (e.g. 0.1mm nozzle, but with longer printing time) or using other 3D printing technologies like SLA (stereolithography) or SLS (selective laser sintering). For example, using the Form2 SLA printer (from Formlabs), we manage to print holes of radii at 0.35mm reliably. In fact, with the rapid advancement of desktop scale 3D printers, we can expect to be able to fabricate porous moulds with smaller hole size with lower cost machines, thereby improving the visual quality of the moulded pulp object.

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