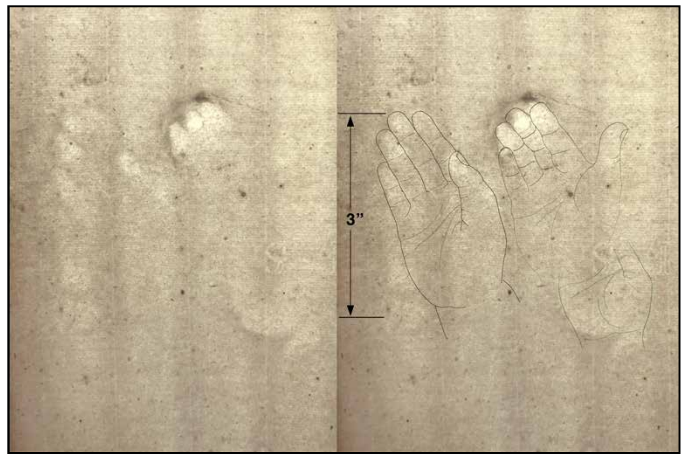
3D printing a watermark celebrating the 31st anniversary of the *British Association of Paper Historians*

In the beginning, there was the **watermark.** The Lord said, "Let there be light and shade." And so it was. Variations of fiber density exist in every sheet of laid paper ever made by hand. The laid lines themselves are a sort of watermark.

Stand at a vat, form a sheet, pass the mould to the coucher along the stay, lift the deckle, (still dripping wet), fit the deckle to the sister mould, in front of you on the bridge. Form another sheet. Well done, but wait, just a few seconds earlier, as you removed the deckle, drips fell onto your newly-formed sheet displacing fibers, making divots in that attractive sheet you so lovingly made. The droplets' violent collision displace fiber just as an asteroid makes craters on the moon. These "vatman drips" land on the felt side.

The coucher, too, may permit drips to fall from the mould as he couches your sheet. The only difference is that the coucher's drips land on the wire side, interrupting the laid screen pattern. I must point out that the laid screens sewn to the ribs of your two moulds are getting old, some of the laid line wires are out of place; some lifted and some dented. As is sometimes the case, your first couched sheet of a post produces a few air pockets. Your young coucher's assistant, the "upper-end boy," pats down the domed bubbles, displacing fiber and making yet another discernible mark in the paper seen when held to light - a watermark of a handprint.

Holding your sheet to the light, you can see the raised wires and drips form lighter areas in the paper, and notice the dark lines made by the dented wires. You could use this information to invent and design the first-ever wire watermark.

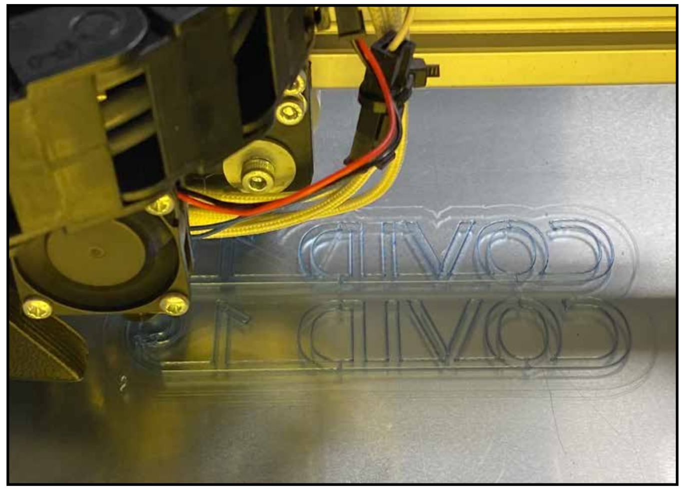


Air bubbles tamped down in page of a 17th c sketchbook (child-size hand)

This technique of yours has grown more articulated and complex these last 600 years—watermarks have become more intentional, imbued with meaning, and use sophisticated, complex technologies and devices. Watermarks are used as identifier devices in various ways, i.e., designating a manufacturer, a specific vat man, a paper format or type, as an anti-forgery device, or for vanity and status.

Types of watermarks include wire watermarks[1] (aka line watermark), light and shade[2] (aka chiaroscuro or shadow), tonal watermarks[3], (aka cylinder mould watermarks); as well as the complex and varied techniques developed in China and Japan, i.e., Sukashi. Copious watermark patents found in a quick search of the US Patent Office support my claim that watermarking is a deep and relevant subject. Nick Pearson, a friend, and treasured resource in all things paper (and tea) was issued a patent for a new watermark technique as recently as 2018.[4]

COVID 19



Creating an experimental 3D printed wire watermark

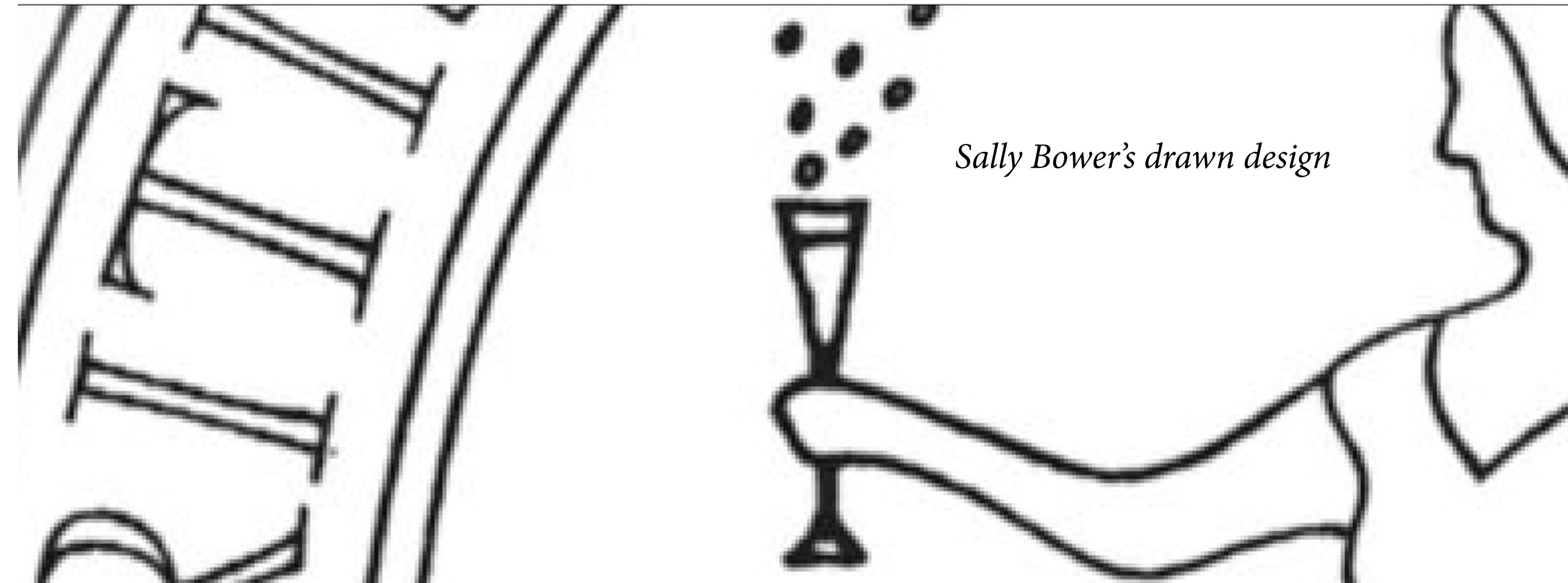
There exist many types of 3D printers;[6] at Magnolia Editions, we use Fused Deposition Modeling (FPM, aka FFF) printers. FPM printers extrude a bead of hot plastic, slowly building up an object similar to making a coiled pot. However, because a wire watermark has a low profile, the printing process happens fairly quickly – typically in less than 15 minutes. The file preparation, on the other hand, can be arduous, tedious, and time-consuming.

The Back Story: 3D printing a revised BAPH watermark with champagne glass and bubbles

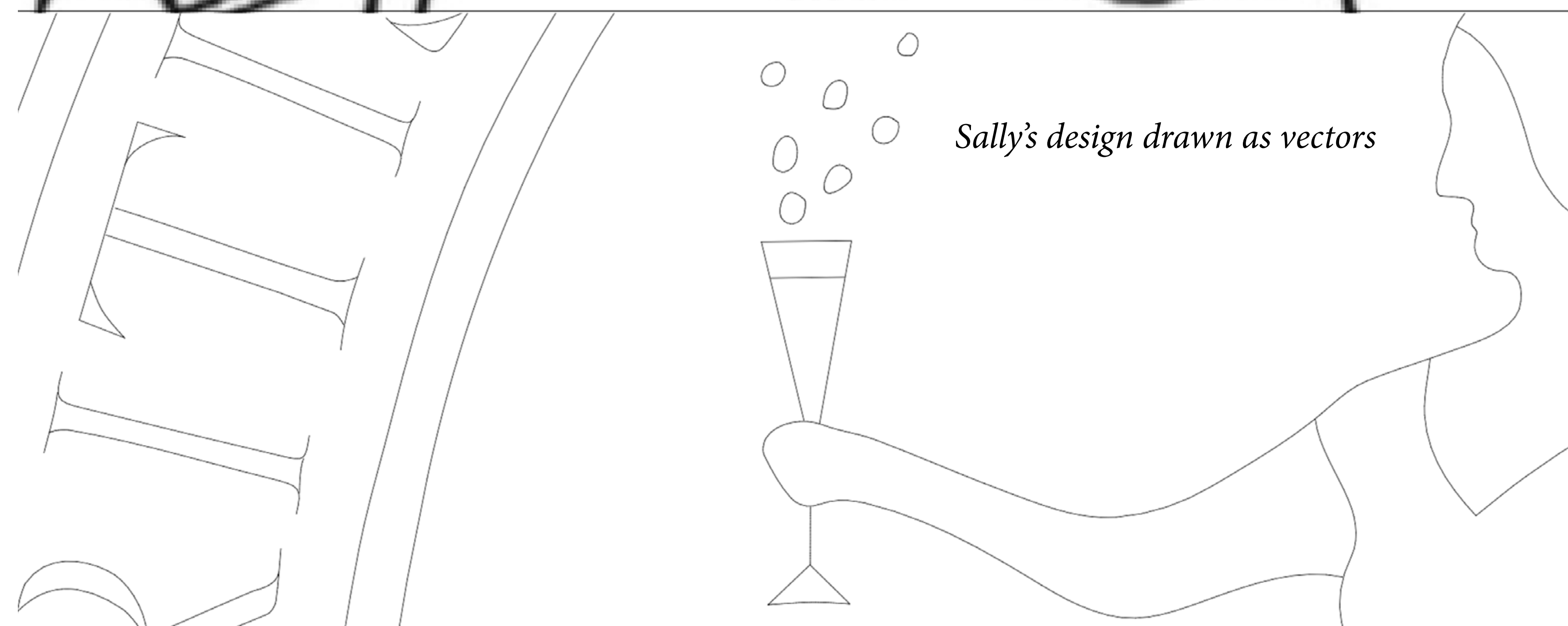
To pass the time while in isolation and to make lite of a dire situation, I sent Peter Bower an early draft of a paper on Renaissance-style hemp toilet paper bearing the watermark COVID-19, a commemorative toilet paper project. In the article and my emails to Peter, I describe 3D printing of the COVID-19 watermark. Peter replied, asked if a more complex watermark would be feasible: specifically, a Sally Bower redesign of her original, rather intricate BAPH emblem. In the restructuring, Sally had replaced the laurel branch with a bubbling champagne glass to celebrate the cover of the 50th issue of The Quarterly.

The first step to discover feasibility was to translate Sally's traditional pen and ink drawing into a computer vector

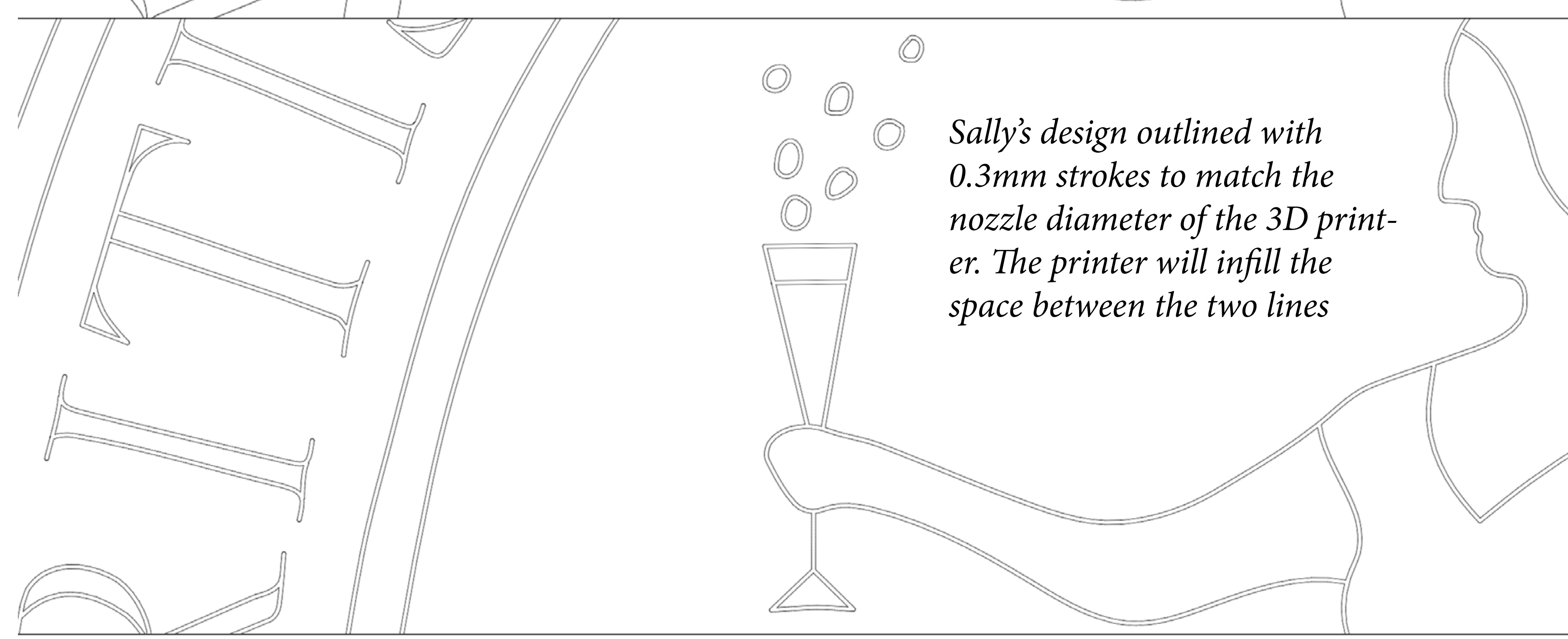
graphic – that is, get the design drawn as lines, points, and curves expressed in mathematical equations, not a raster (pixels). There is no automatic tracing program that works well for this – at least not yet; Artificial Intelligence will likely someday come to our aid. So, I "redrew" the image into Adobe Illustrator, "hand" tracing vector lines over a scan of Sally's drawing. Not wanting all the letters and elements to fall apart, I drew connecting lines to hold it all together and placed the file in the capable hands of Magnolia Editions' Master Printer, Nicholas Price.



Sally Bower's drawn design



Sally's design drawn as vectors

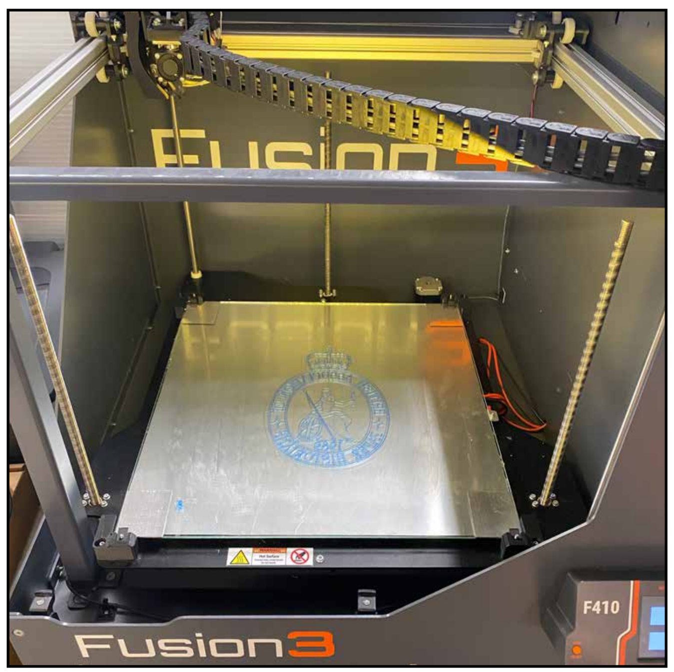


Sally's design outlined with 0.3mm strokes to match the nozzle diameter of the 3D printer. The printer will infill the space between the two lines

Nozzle diameter:

Our studio's 3D filament printer accepts, among other plastics, PLA (polylactic acid) and ABS plastic filament. For this watermark, we installed a spool of PLA filament, which feeds the hot print head. Inside the print head, the PLA is brought to the melting point and extruded onto a heated, flat glass bed. Most 3D printer extruder print heads move on x and y axes, and the bed on the z-axis (up and down).

Our Fusion3 printer extruder has a 0.35mm orifice. This diameter is critical to keep in mind when "modeling" the watermark: although it can print 0.35mm beads side by side and on top of one another, it cannot print half a line or any fraction of a width. For this reason, Nicholas, after scaling the 2D design to 9 inches in height he made the vector line stroke 0.35mm. Next, he changed the single line design to an outline (a double



line). He then joined every line segment to make a solid, contiguous watermark.

With the watermark represented as double 0.35mm lines, Nicholas imported the 2D Adobe Illustrator watermark into Fusion 360. This software allows him to manipulate the watermark in 3D. Extruding the 2D lines gives the watermark its thickness. The 3D model is then exported out of Fusion 360 into yet another program, Simplify3d, an application used to slice the model into individual layers. Each layer printed is 0.2mm tall. Therefore, our 1mm watermark requires five layers ("slices").

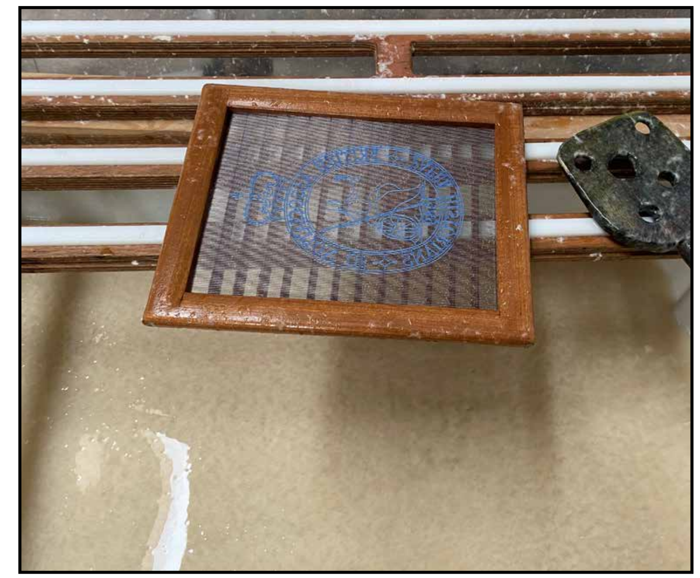
This thin profile is considered "experimental" by Fusion3 technicians - and by most-print-for-hire companies; many of whom refusing to touch his project. Regardless, we push forward.

Next, Nicholas translated the layers into the printer movements – the paths the head must follow to draw the layers and build our watermark. These instructions take into account the size of the nozzle, the type of material, head speed, and the material's melting point; such instructions for how the printer moves are called "G-code."

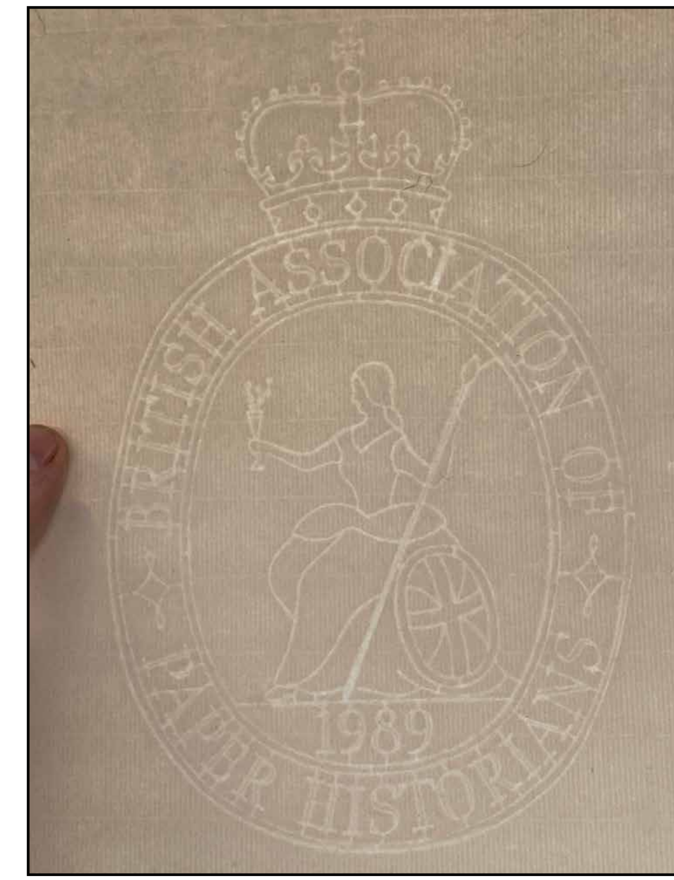
With the filament loaded and the printing instruction initiated, the Fusion3 printer heats both the bed and print head, spitting out some filament as a test – a curl of hot plastic spiraling from the print head to the bed below. This tangle cools and becomes rigid quickly and is discarded. Counter-intuitively, the machine's next move is to wait for the head to cool off. When cold, it raised the bed 15 inches to the print head height, and a sensor on the print head touches off on each corner to check and calibrate the bed to level. Next, we again wait for the print head to reheat to temperature. Once the two components have warmed to operating temperature, the printing begins in earnest.

A 3D watermark is drawn one layer at a time, built up layer upon layer, like a coil pot; thus, the watermark becomes a reality. Abruptly, on finishing "build," the bed lowers to the machine floor – 15 inches below the x, y plane of the print head. The completed watermark is stuck to the bed and is coaxed free with moisture and a spatula.

I attached the watermark to the laid screen of the mould with spray cement augmented with twists of brass wire. With my vat charged with very free flax and hemp furnish (beaten hard and fast), I formed and couched 12 sheets in rapid succession. Looking at the wire side of the newly formed sheets with perfect right reading impressions of BAPH insignia was inspiring; if I were not



already a member, I would have stopped and joined on the spot. The crisp impressions seemed to demonstrate the viability of watermarked/laid screen to be entirely viable. However, one never knows, not really – not until the sheet is dry and back-illuminated.

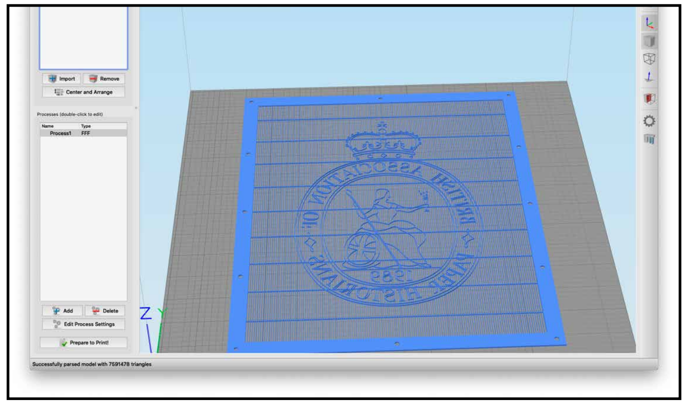


As lovely as the look-through[5] was, the support lines are so numerous that they utterly distract from the beauty of the BAPH emblem, sadly making this first attempt unacceptable.

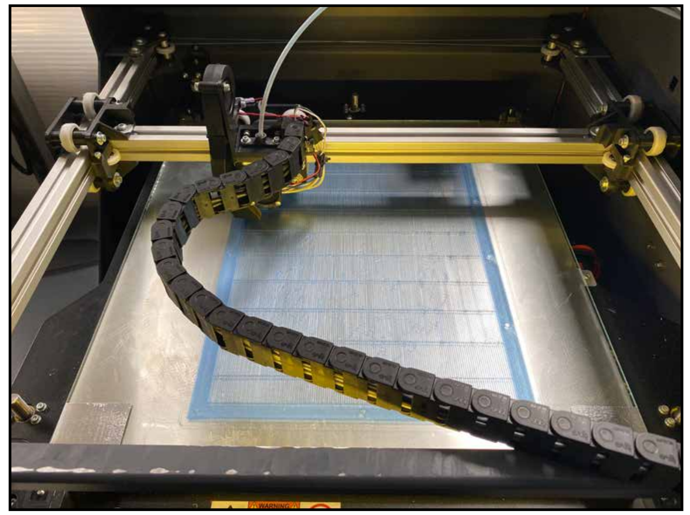
Cutting away each support line and sewing down each element in the correct location seemed to be the difficult but logical next step. Thankfully Nicholas reminded me of earlier experiments (done using Brian Queen's removable screen 3D printed mould) where he had printed a watermark as part of a laid screen (fused). This approach seemed to be the truly logical next step; I am, after all, always up for a newer technology augmenting an older technology.

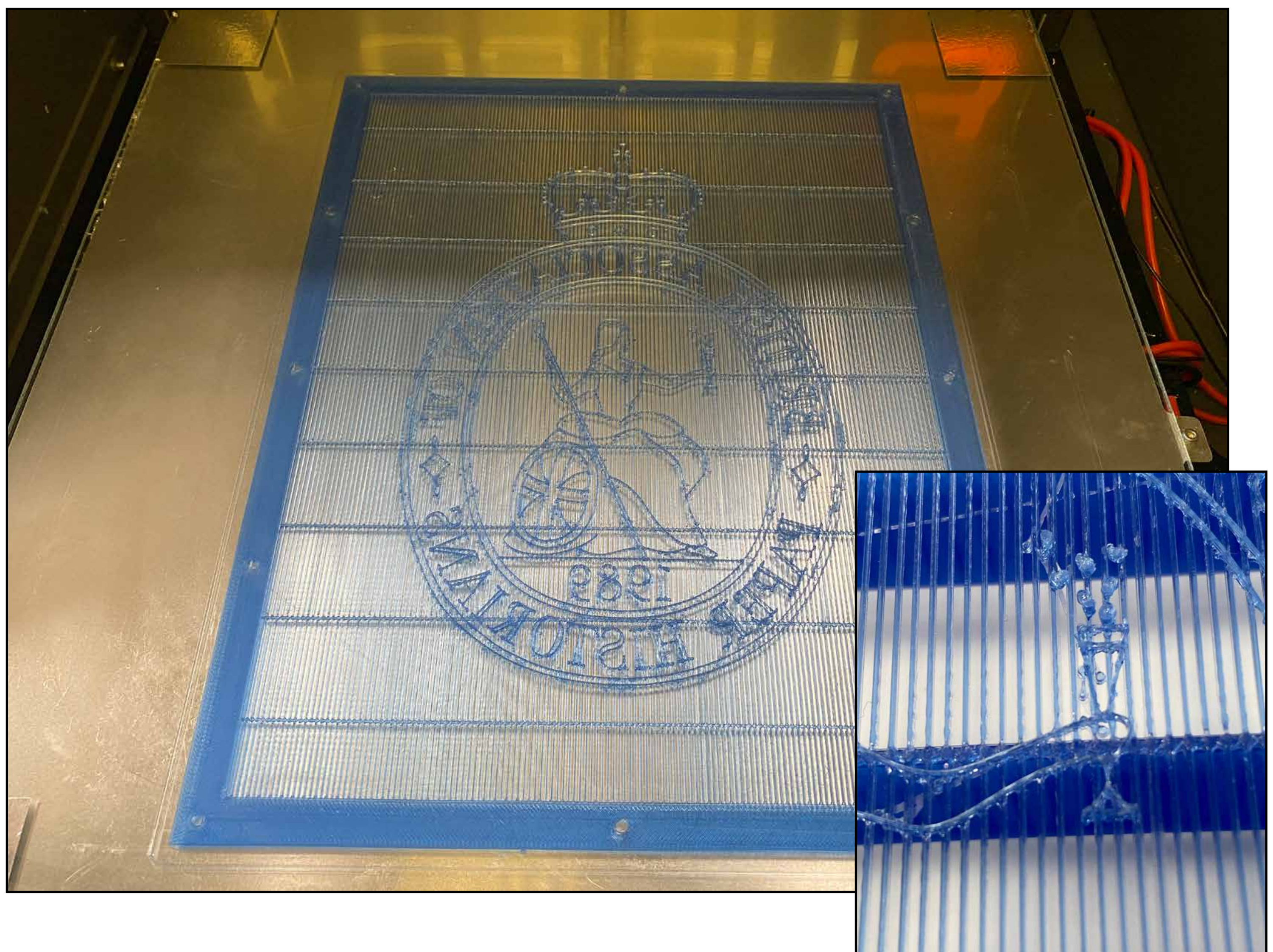
Back to the 3D drawing board

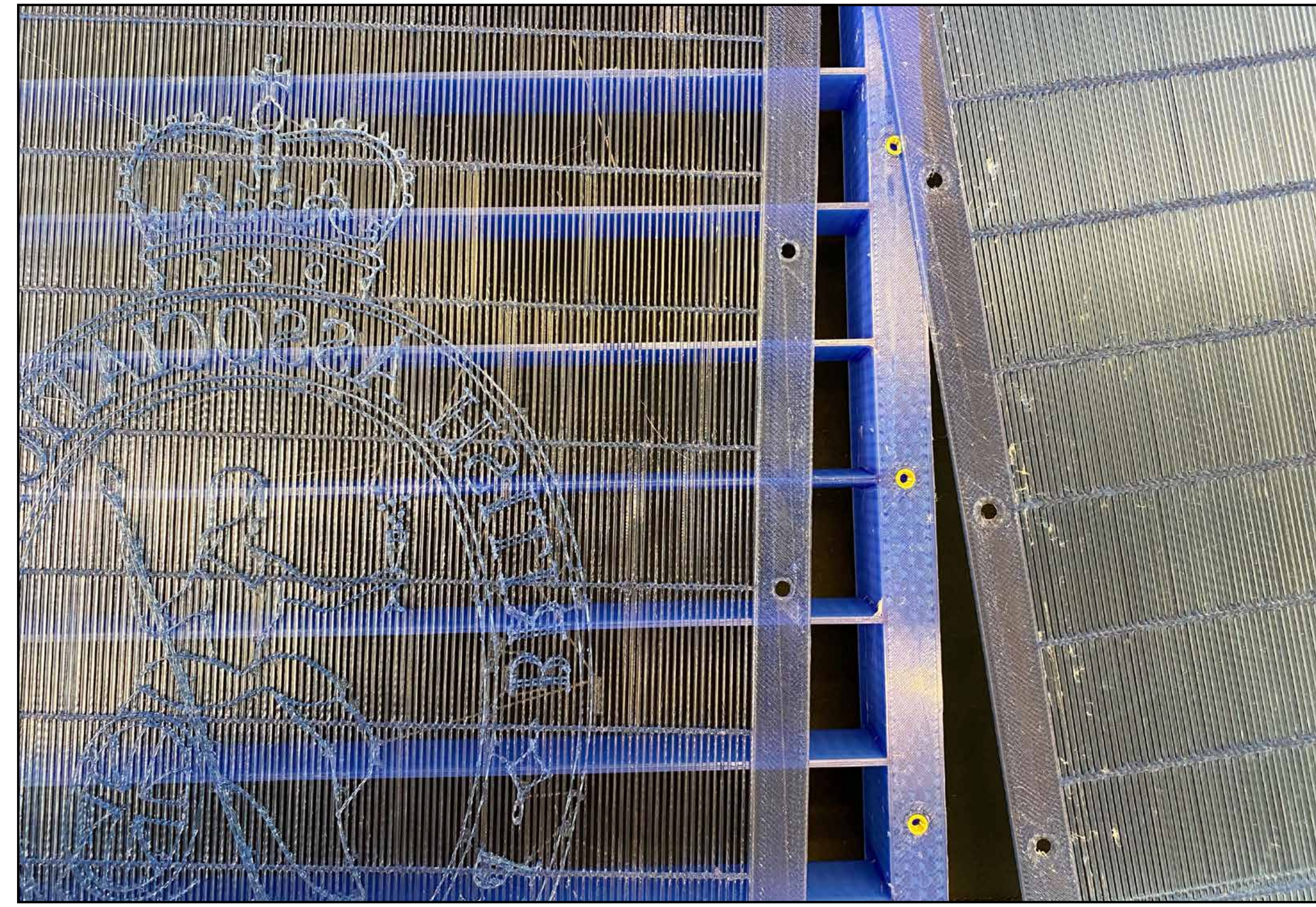
Nicholas reworked the file and joined the BAPH watermark to a 3D model of a laid screen modeled to fit an 8.5 x 11-inch mould and deckle (designed by Brian Queen). The joining was problematic and took a few days of troubleshooting and problem-solving. Once a successful file was created and the G-code sent to the Fusion3 printer, the build took four hours to complete.



The chain and laid lines printed first, followed by the watermark. The completed watermarked-laid-screen built layer upon layer without problems – surprising, considering the watermark had to span the gaps between the laid lines. Extruded hot PLA can only span tiny distances before slumping and ruining a build.

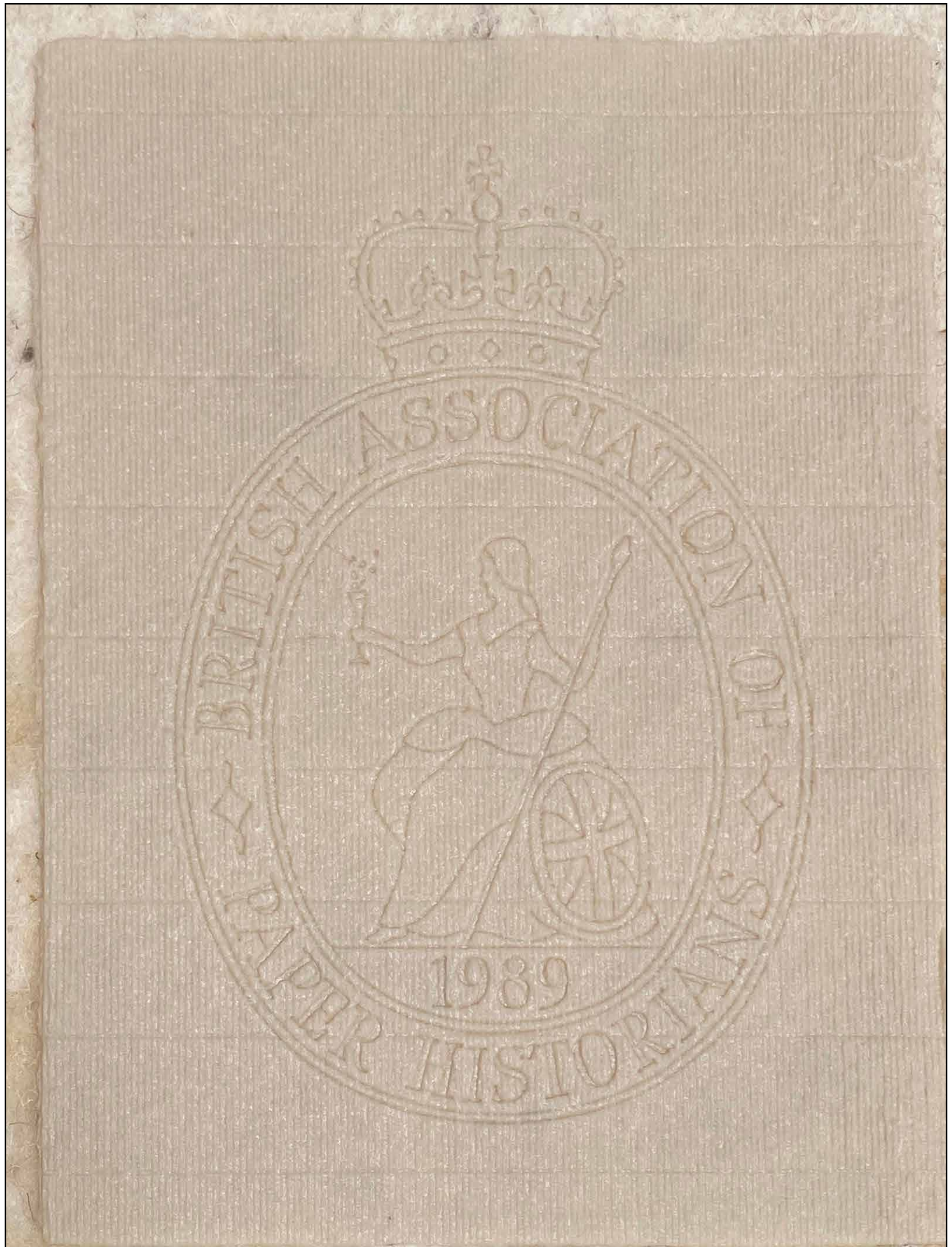






Swapping out the old screen with the BAPH watermarked laid screen (12 screws).

Mould and deckle with watermark infused laid screen and four couched sheets on Fabrianesi and Apenninica wool felt.



Above: A freshly couched BAPH marked sheet. Opposite: Shorter furnish fibers might improve the letter form detail.

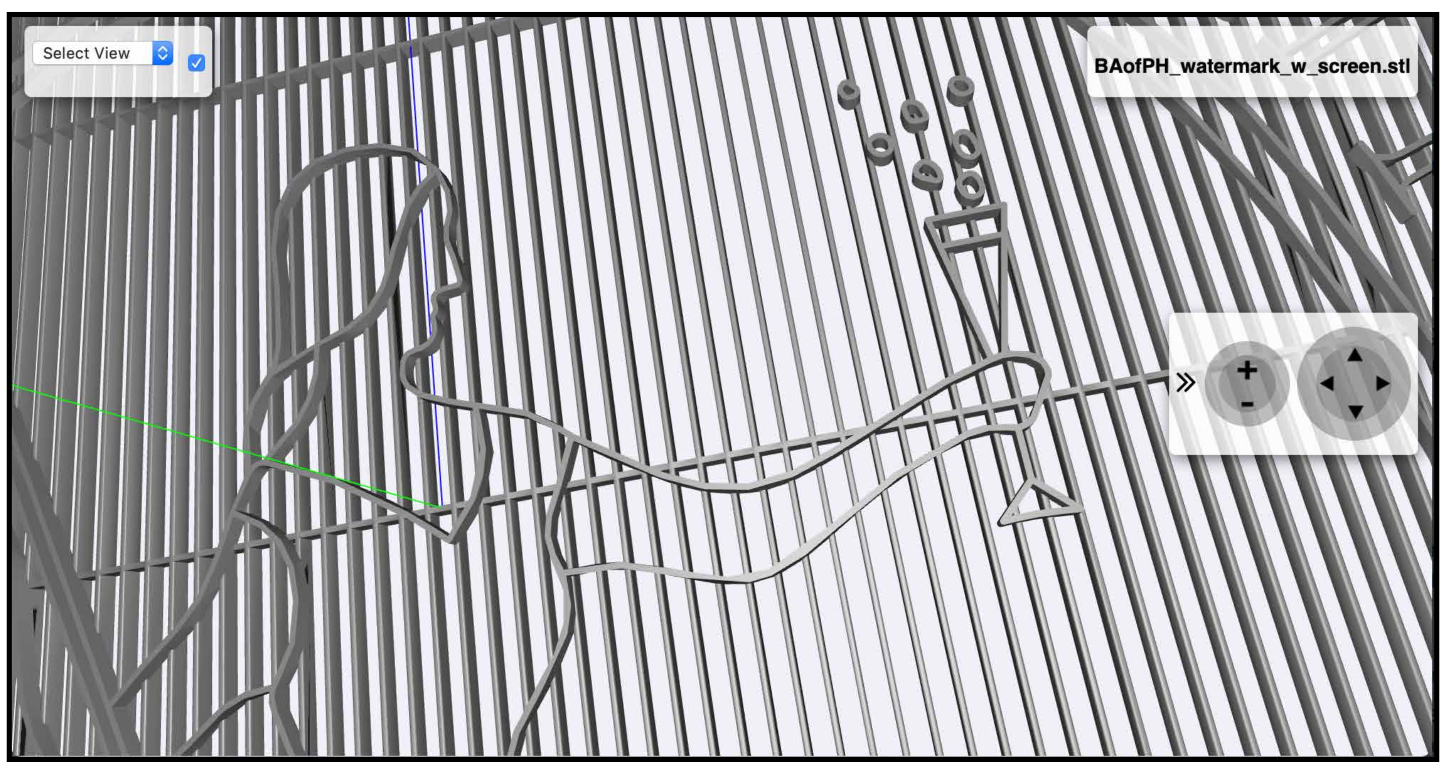
The results of our in-house printing of the unitized screen and watermark using our fused filament fabrication (FFF, aka FPM) printer are acceptable – But can we do better? Perhaps a more industrial printer could provide us with a more detailed and hard-edged result.

3D Prototyping Providers

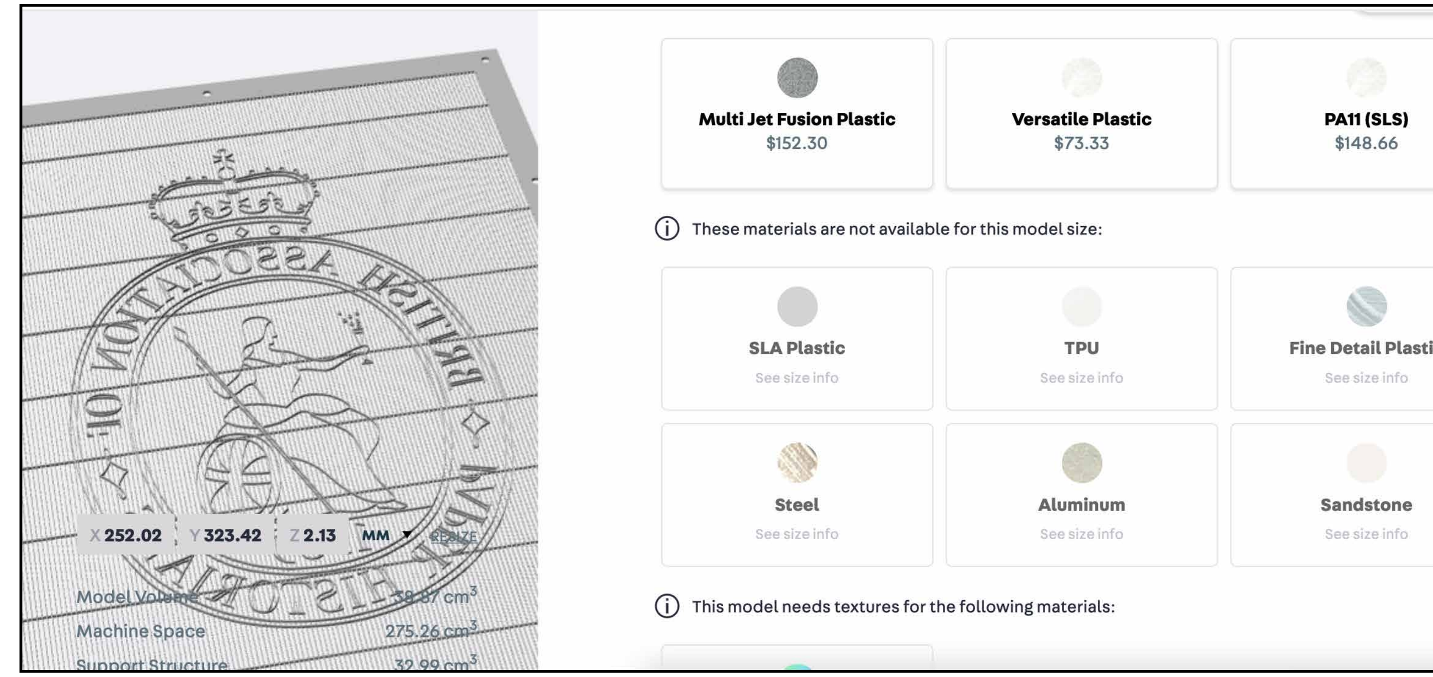
June 1, 2020:
Many companies provide 3D printing services and offer prototyping in a variety of materials. With much of the heavy lifting complete, specifically the modeling of the laid screen/fused BAPH monogram into a .stl file, I ventured online. I chose a printing service: Shapeways for sintering in nylon and Craftcloud for 3D lithography printing in resin. Furthermore, I inquired about the possibility of printing the watermarked screen in metal. Uploading the STL file of the watermark was easy – within a minute or two, I was inspecting the model in my browser, in 3D, rotating, zooming, etc. In about the same number of minutes, they had my money. The renders from the two companies look sharp and clean. In time I will know if their builds match my expectations.

June 6, 2020:
Let us remember; we are attempting and, in some cases succeeding, in printing screens with single or double strands of PLA, a feat the printer manufactures and printing services describe as "experimental," as I mentioned earlier. With that in mind, I now report to you, dear reader, Craftcloud engineers rejected the .stl file (with its one strand 0.35mm laid lines) for both resin and metal fabrication in China. Craftcloud, however, has not given up and is still reaching out to other 3D printers to find one brave enough to attempt printing our file.

-Don

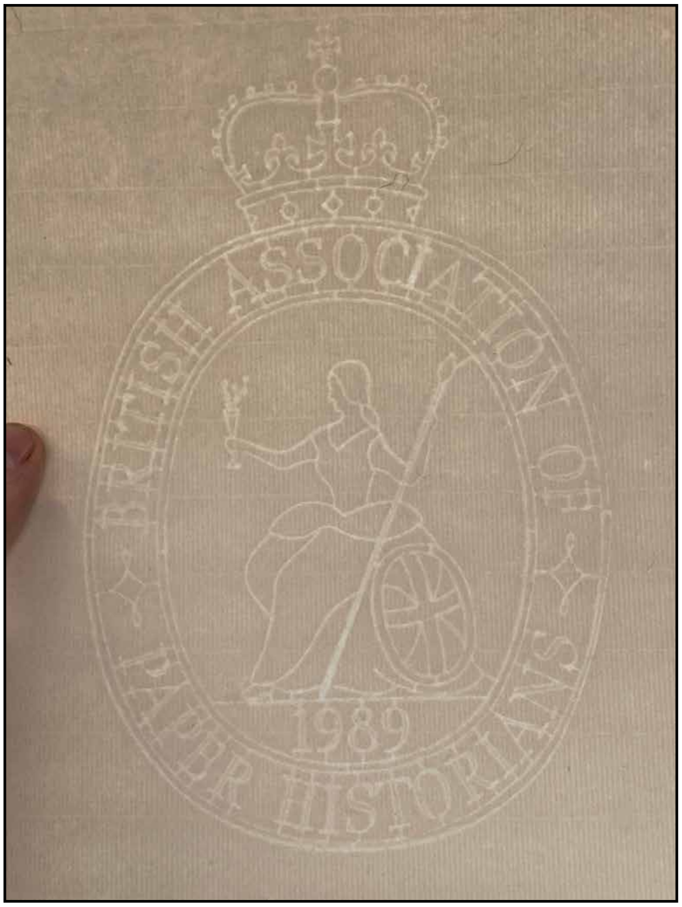


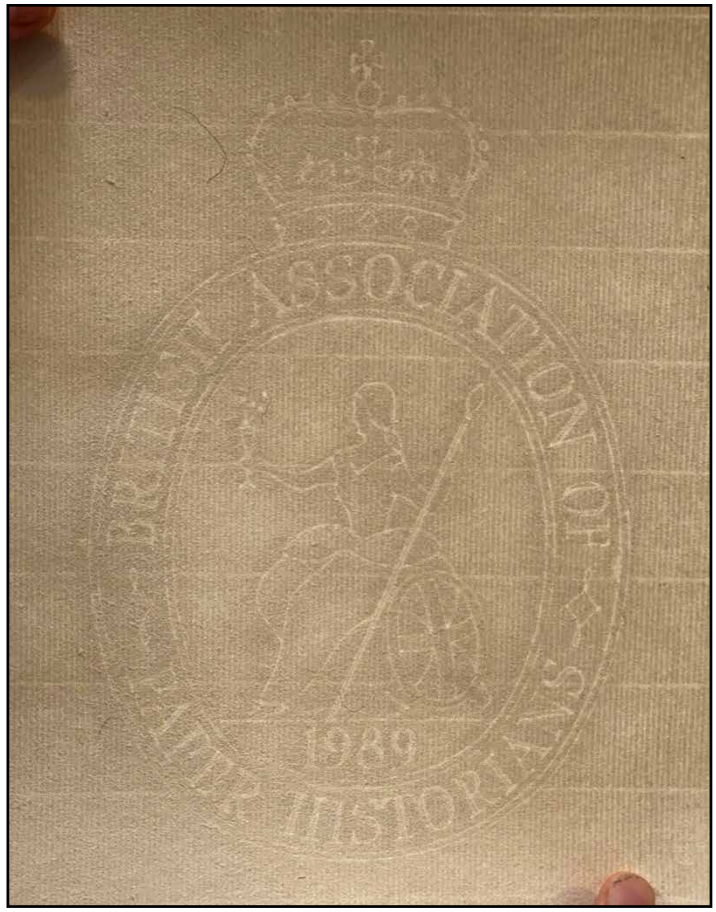
Craftcloud browser render detail



Sdhapeways browser render

With the numerous failures under my belt, it may be time to attempt something difficult to accomplish with brass wire and restively easy for 3D printing. Making a wire watermark with tapered lines, like a quill pen might make.





With and without support wires

Notes:

1. The wire watermark is shaped wire bent into a design and sewn on to the mould screen covering (or onto a dandy roll screen). The shaped strands of wire lay on a flat plane - usually not overlapping but rather cut, starting and stopping on either side of an intersection. The shaped wire makes for thinner, more translucent areas so that the design is visible when looking through the sheet (via transmitted light).

2. Light and shade watermarks employ various techniques, including electroplating carved wax and acid etching, to emboss the wove screen on which the paper is formed.

3. Tonal or cylinder mould watermarks made with relief areas on the cylinder, then calendared when dry, rely on paper density for a tonal image in a paper of consistent caliper.

4. The watermark patent titled: ***PAPER INCLUDING ONE OR MORE MULTI-TONAL WATERMARKS HAVING FULL TONALITY, AND AN IMPROVED WATERMARKING TOOL FOR MANUFACTURING SUCH PAPER,*** granted in 2018, to the inventor Nick Pearson, a living treasure in the papermaking world. (Patent No. 20180258588)

5. Look-through: If a watermark (held to light) is well articulated, we call this a "good look-through." Shorter fibers provide better look-through than longer fibered furnishes. This term can also refer to the clarity of the laid, herringbone, wavy, or wove mould covering screen as well (the mould's screen covering is, itself, a sort of watermark).

6. 3D printer types:
Stereolithography (SLA)
Selective Laser Sintering (SLS)
Fused Deposition Modeling (FDM)
Digital Light Process (DLP)
Multi Jet Fusion (MJF)
PolyJet
Direct Metal Laser Sintering (DMLS)
Electron Beam Melting (EBM)