3D Printing a Champagne Watermark Celebrating the 50th issue of the BAPH Quarterly

In the beginning, there was the ***watermark.*** The Lord said, "Let there be light and shade." And so it was. From then and forever, variations of fiber density exist in every handmade sheet of paper. Cellulose fiber in these durable leaves accurately reveals a story of the vatman, his coucher, the felt maker, and the finisher. They tell of the mould maker whose laid screen is forever visible when held to lambent light. Indeed, paper with or without markings, remembers the human saga of innovation and experimentation. And we saw that it was good.

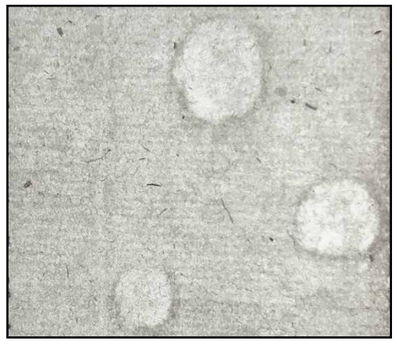
Stand at a vat, form a sheet, pass the mould up the stay to the coucher while lifting the dripping wet deckle from the mould. Fit the deckle to the sister mould, in front of you on the bridge. Form another sheet. Well done, but wait a few seconds earlier, as you removed the deckle, drips fell onto your newly-formed sheet displacing fibers, making divots in that attractive sheet you so deftly fabricated. The droplets collided with the paper's surface, displacing fibers just as asteroids

Vatman's drip marks made on the felt side while sheet is draining;

The look-through of a vatman's drip (aka, tear)

make craters on the moon. These "vatman-drips" land on the felt side. The coucher may also sprinkle the paper drips that fall from the mould as he couches your sheet. The difference is that a coucher's drip has a stronger edge and, because it lands on the wire side, it interrupts the laid screen pattern.

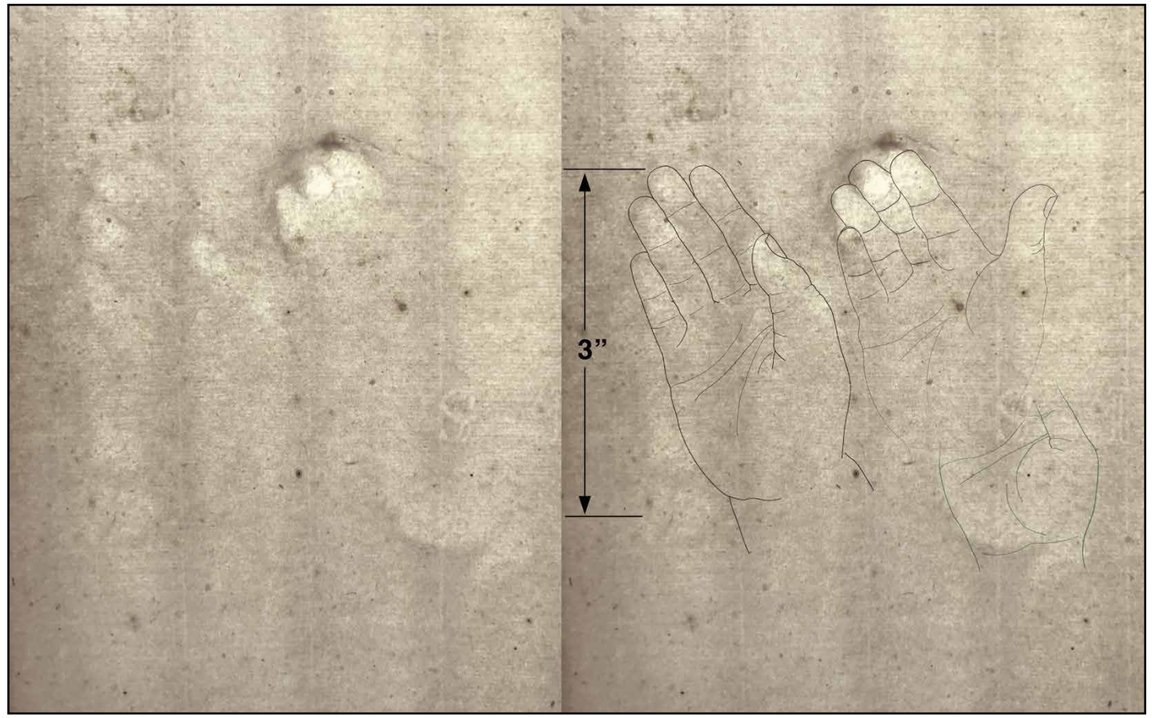
Coucher's drip on the wire side of a couched sheet; at right, a similar sheet after drying.



The look-through of a coucher's drip (aka, tear)

I want to point out that your moulds are old and worse for wear. The laid screens of your two moulds have often been repaired, some of the laid line wires are out of place; some lifted and some dented. Holding your finished sheet to the light, you can see that the raised and depressed wires and drips form lighter and darker areas in the paper. Even the repairs are discernible. You wisely employ this information to invent one of the first-ever wire watermarks. You bend a wire to the figure "8" and sew it to the mould surface. Eight is now a watermark in every sheet you make. Symbolic of the resurrection and the hexagonal baptismal font. How appropriate choosing "8"; symbolizing the transformation of rags by baptism, and here you are "birthing" 1000 sheets a day, 2000 on a good day if the stampers pound around the clock – what an ungodly din!

Figure in the Form of the Arabic No. 8, c. 1293 (Fabriano Paper Museum)



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

There is another interesting flaw in that very first sheet. It is not uncommon for the first couched sheet of a post to trap air, forming pockets. Your young coucher's assistant, the "upper-end boy," with good intension, patted down the domed bubbles, displacing fiber, making yet another discernible mark. Seen in the backlit paper – a handprint, a sort of light shade mark - causing a thinning in one area and increased density in another.

It was William Henry Smith in 1848 who devise an efficient way of perfecting that hand print idea into the first viable light & shade watermark by pressing a shape into an annealed wire mesh screen destined to become the surface of a paper mold at Johannot mill. The bas relief accumulated more fiber in the deepest areas and less pulp fibers in the thinnest ones.

So this bent wire technique of yours has evolved, become 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 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 indicate 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]

A 3D printed paper mould gone haywire.

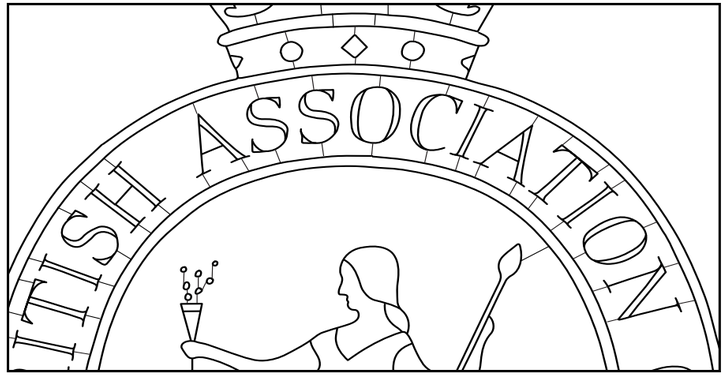
Mother Nature (and the 3rd law of thermodynamics) seems to delight in exposing the chthonian underbelly of our well-thought-out, virtuous intentions. Whenever she does, be sure to look for the fork in the road, disguised as errors and misfortunes. It's not likely you will arrive at a destination worth the journey without investigating the ruts and potholes along the way.

Printing a wire watermark in PLA. The diameter of the extrusion is considered too thin to be successful – not recommended by the manufacturer. "Proceed on an experimental basis."

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.

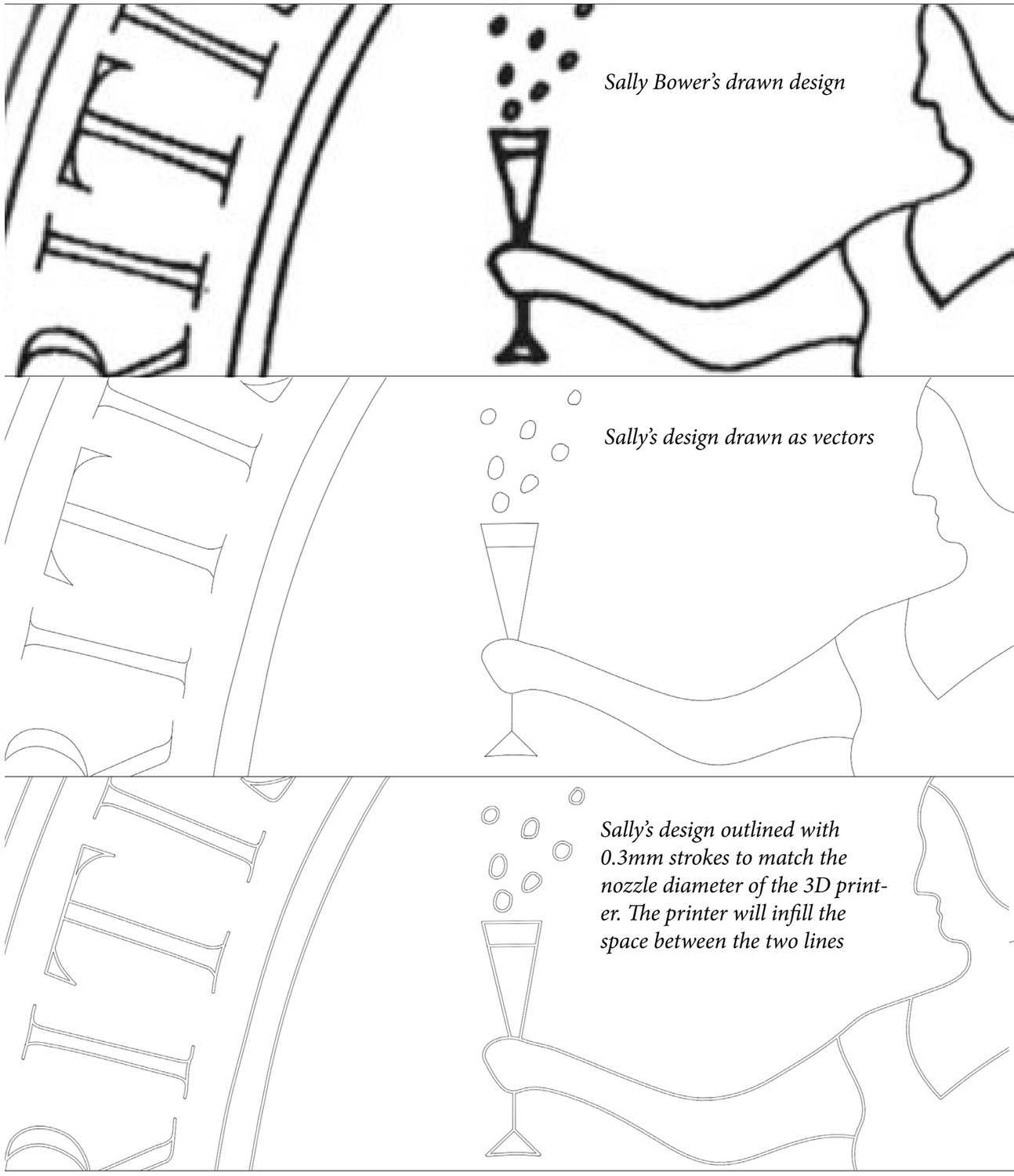
COVID 19



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, asking 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 graceful drawing. Not wanting all the letters and elements to fall apart, I drew connecting wires 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

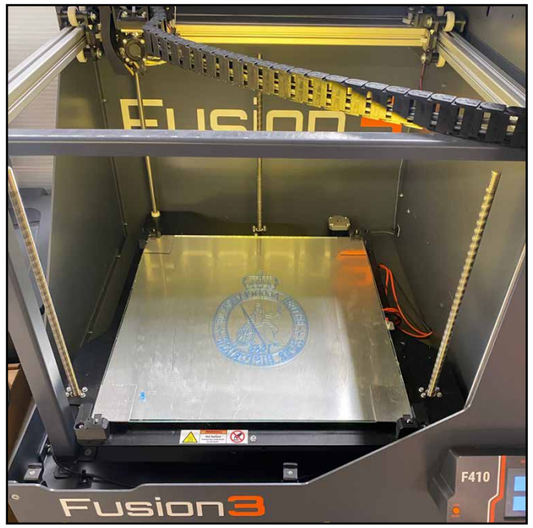
Sally's design drawn as vectors

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. Our 3D printer extruder print head 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, 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.

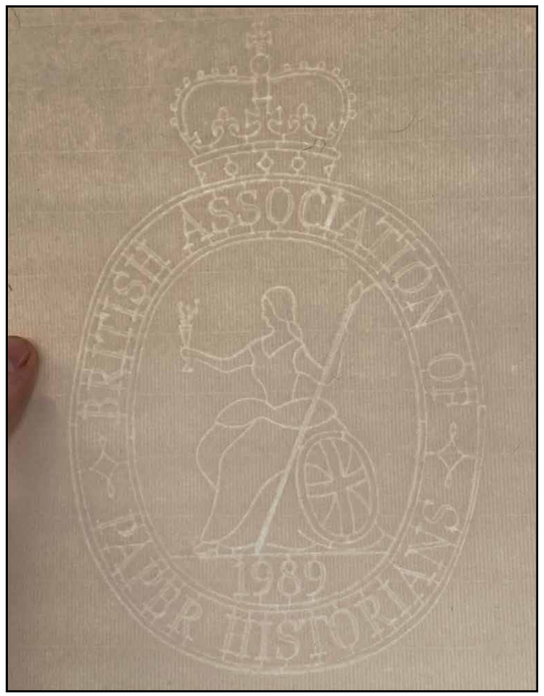
Next, Nicholas translated the layers into the printer movements – the paths the head must follow to draw the layers and build our watermark. These instructions take into account the size of the nozzle, the type of material, head speed, and the material's melting point; such instructions for how the printer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

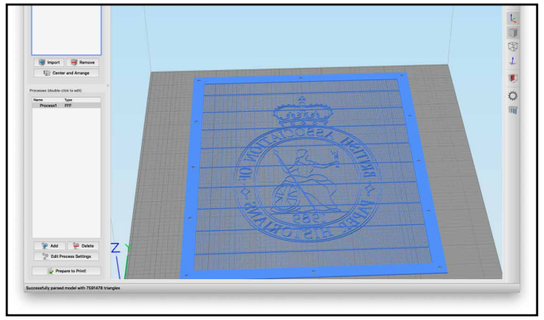


As lovely as the look-through[5] was, the support lines are so numerous that they utterly distract from the beauty of the BAPH emblem, sadly making this first attempt unacceptable.

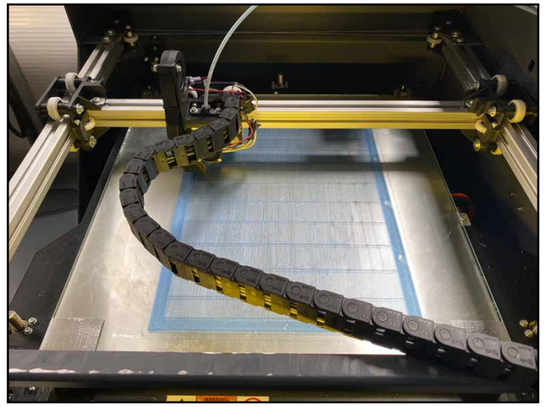
Cutting away each support line and sewing down each element in the correct location seemed to be the difficult but logical next step. Thankfully Nicholas reminded me of earlier experiments (done using Brian Queen's removable screen 3D printed mould) where he had printed a watermark as part of a laid 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.

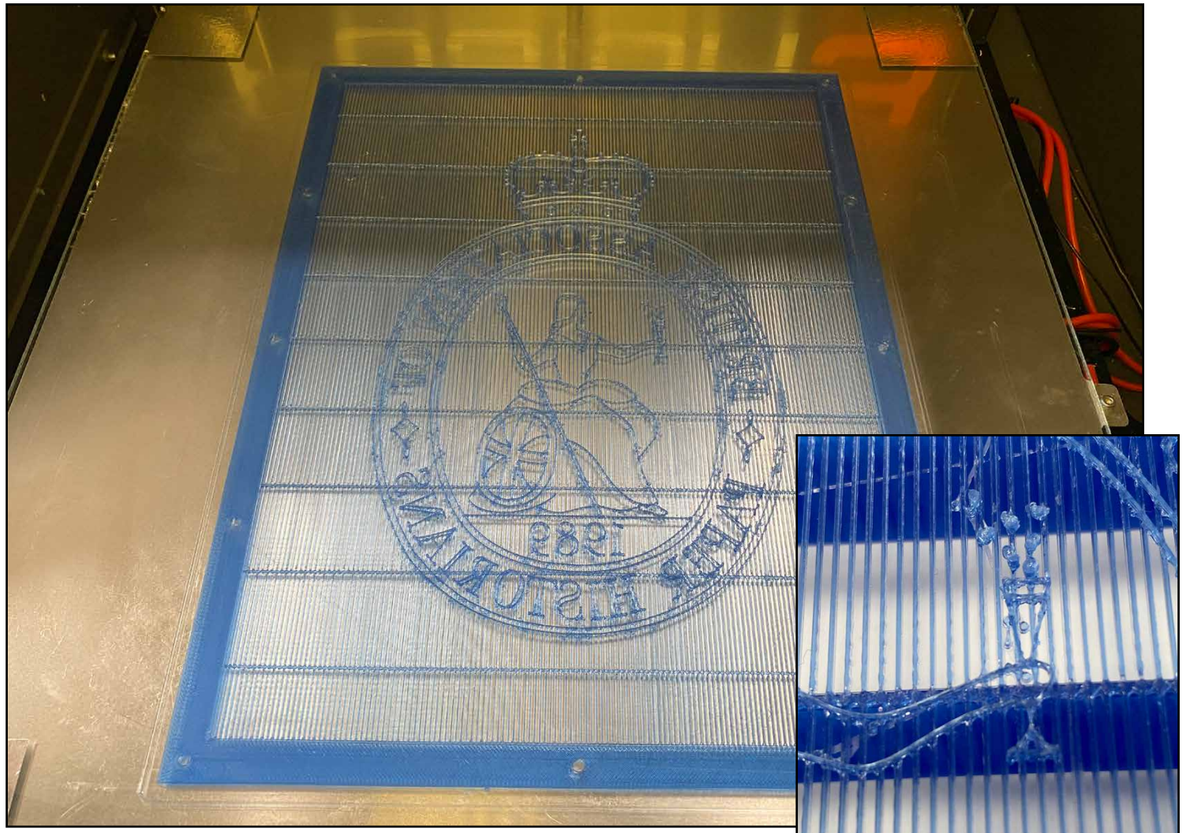
Back to the 3D drawing board

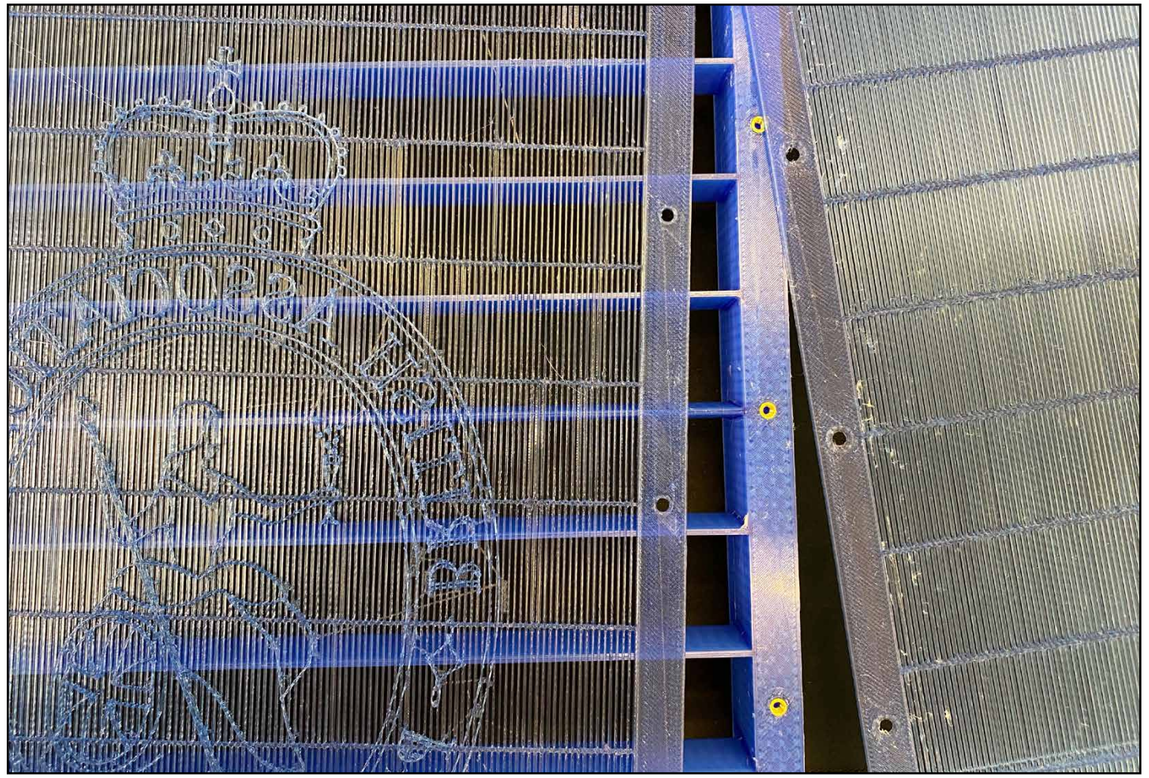
Nicholas reworked the file and joined the BAPH watermark to a 3D model of a laid screen modeled to fit an 8.5 x 11-inch mould and deckle (designed by Brian Queen). The joining was problematic and took a few days of troubleshooting and problem-solving. Once a successful file was created and the G-code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

The Rejections:

All CloudCraft Chinese 3D print services rejectioned our .stl file. The rejections have to do with the width of the laid line wires. We designed our .stl file with 0.35mm width wire lines. Serge Pirard (the fabulous traditional paper mould artisan) has woven me brass laid screens with micrometer reading of 0.225mm wires (even thinner that what I am asking for. The printing services are requesting I re-design the 3D .stl file with wires lines .8mm thick, four times that of a traditional mould built by Serge. It is true that in the Fabriano Paper Museum, have examples of 14 c. paper with very thick laid lines made at a time when drawing wire had not been perfected. I feel we are at that time with 3D printing - the printing of fine lines is not yet developed.

Thick laid lines; Cervo Passante Ramoso di Sei Corna , c. 1360 (Fabriano Paper Museum)

Hi Donald,

This is a friendly reminder that your model "BAofPH_watermark_w_screen" from order "3436842" was taken out of production by one of our 3D printing engineers due to design issues.

To get your model back into production, you can Repair and Update the model yourself or grant permission to Print it Anyway.

Additional details:

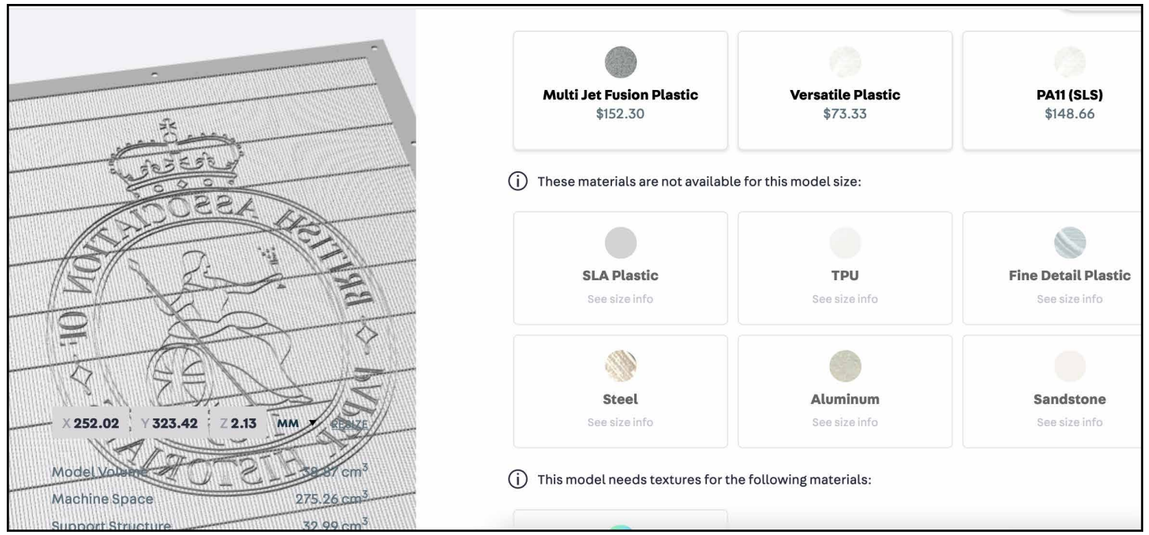
- Rejection issue: Thin Wires
  Rejection description: The highlighted areas in the attached picture are at risk of breaking. The wires in your model are too thin for the current geometry and cannot withstand our manufacturing process without breaking. During the intense cleaning process, we blast the model with air and glass beads to achieve powder-free model. While, for processed and premium finishes, we polish the model with thousands of ceramic pellets. The design may be more successful if the weak areas are thickened. We encourage you to alter your design to ensure a successful print. Please consider these options: 1. Thicken the minimum supported wires, for Natural Versatile Plastic, to be greater than or equal to 0.8 mm. 2. Thicken the minimum supported wires, for Processed & Premium Versatile Plastic, to be greater than or equal to 0.9 mm. 3. Thicken the minimum unsupported wires for all finishes to be greater than or equal to 1.0 mm. 4. Reorder the model with the "Print it Anyway" option selected, in which case we will ship as is. In this option, we will print the model trying our best to create it to your specifications. There may be possible fragmented or missing geometry depending on the thinness of the wires. Always consider the size of your model and reinforce your wires if it is needed. Please, remember that the minimum guidelines will not be adequate for large models. To learn about 3D model printability checks please follow: http://shpws.me/MdWT For more information on design tips and guidelines, visit: https://www.shapeways.com/materials/versatile-plastic

Reference image(s) attached.

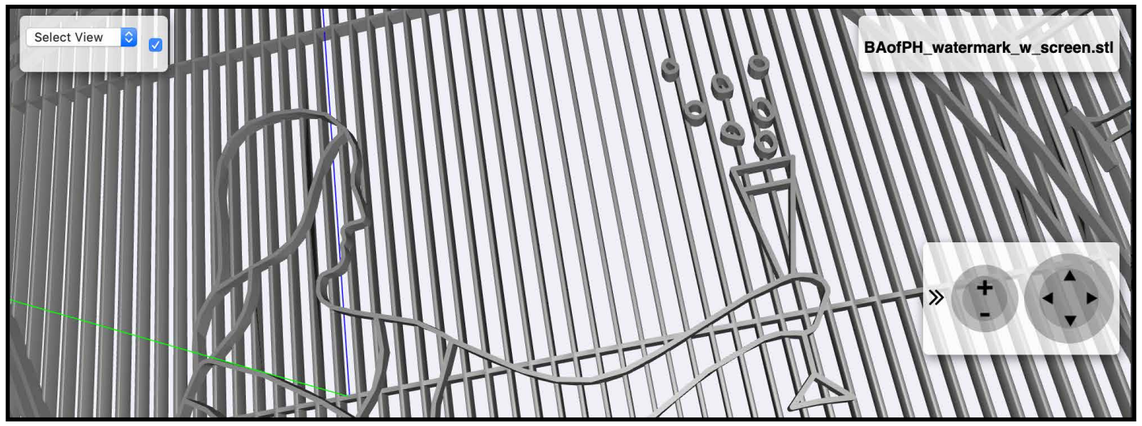
Affected materials:

- Natural White Versatile Plastic
- Polished White Versatile Plastic
- Black Versatile Plastic
- Dyed Versatile Plastic

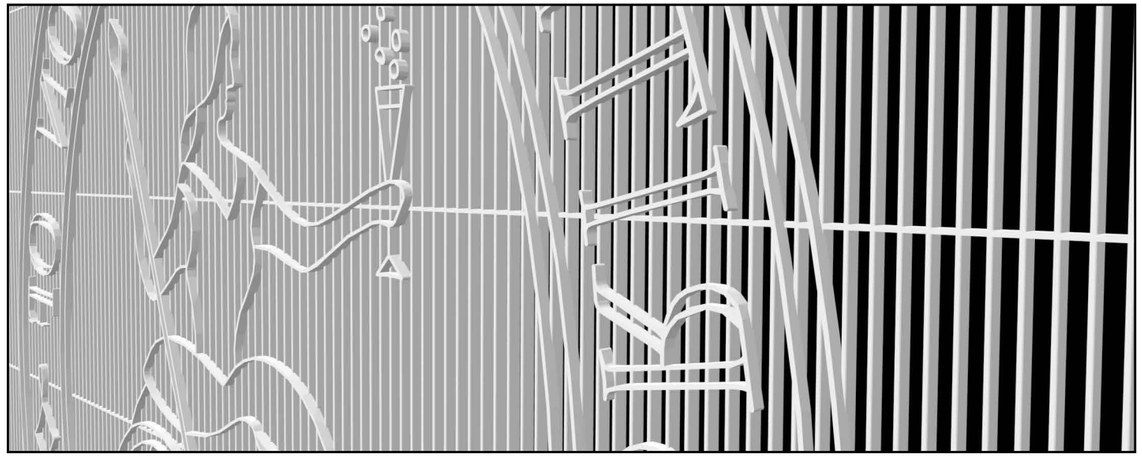
If no action is taken, this model will be removed from your order in 3 calendar days. If you would like to remove this model from the order now, you can visit the model update page and get the rest of your order back into production.



Shapeways browser render

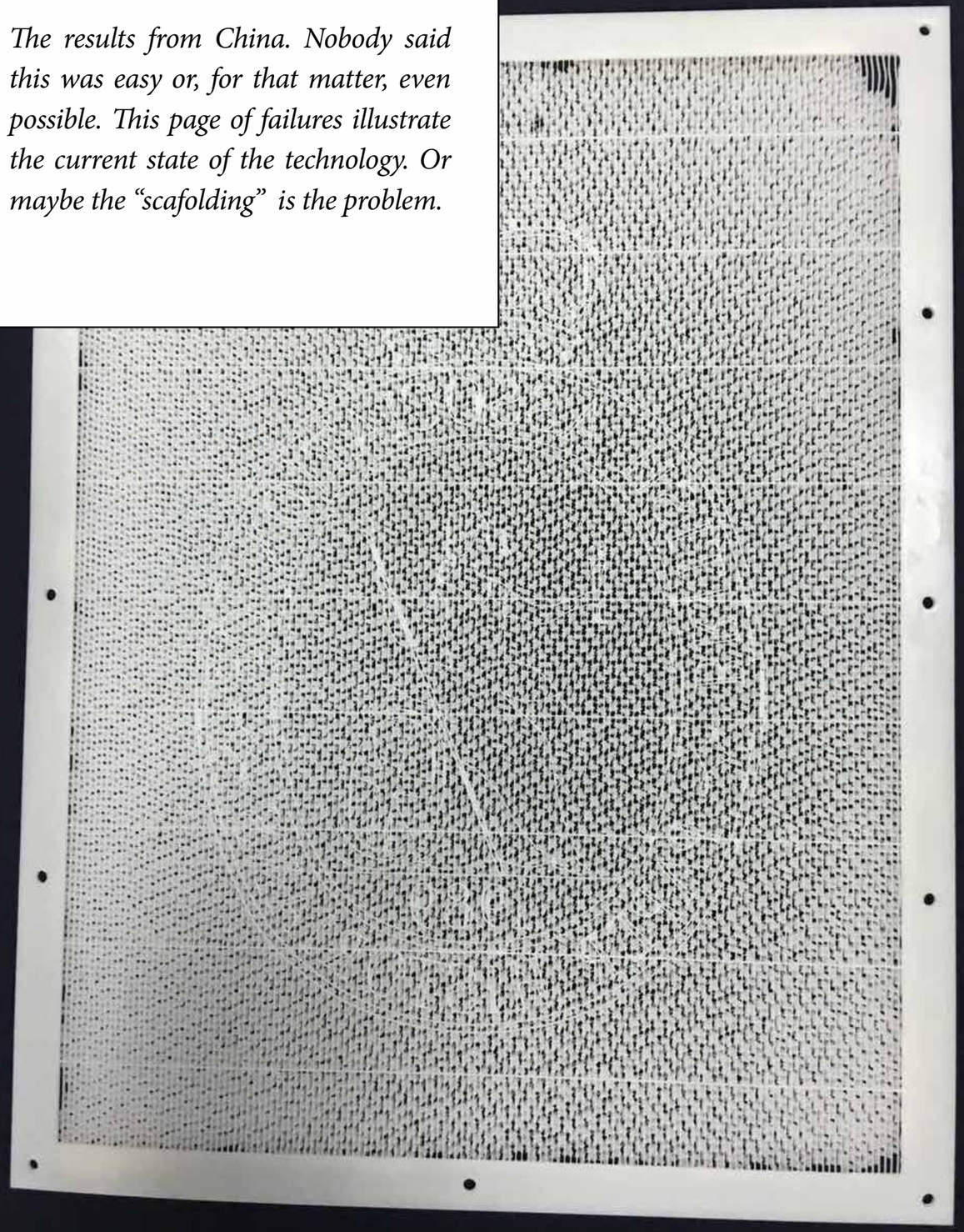


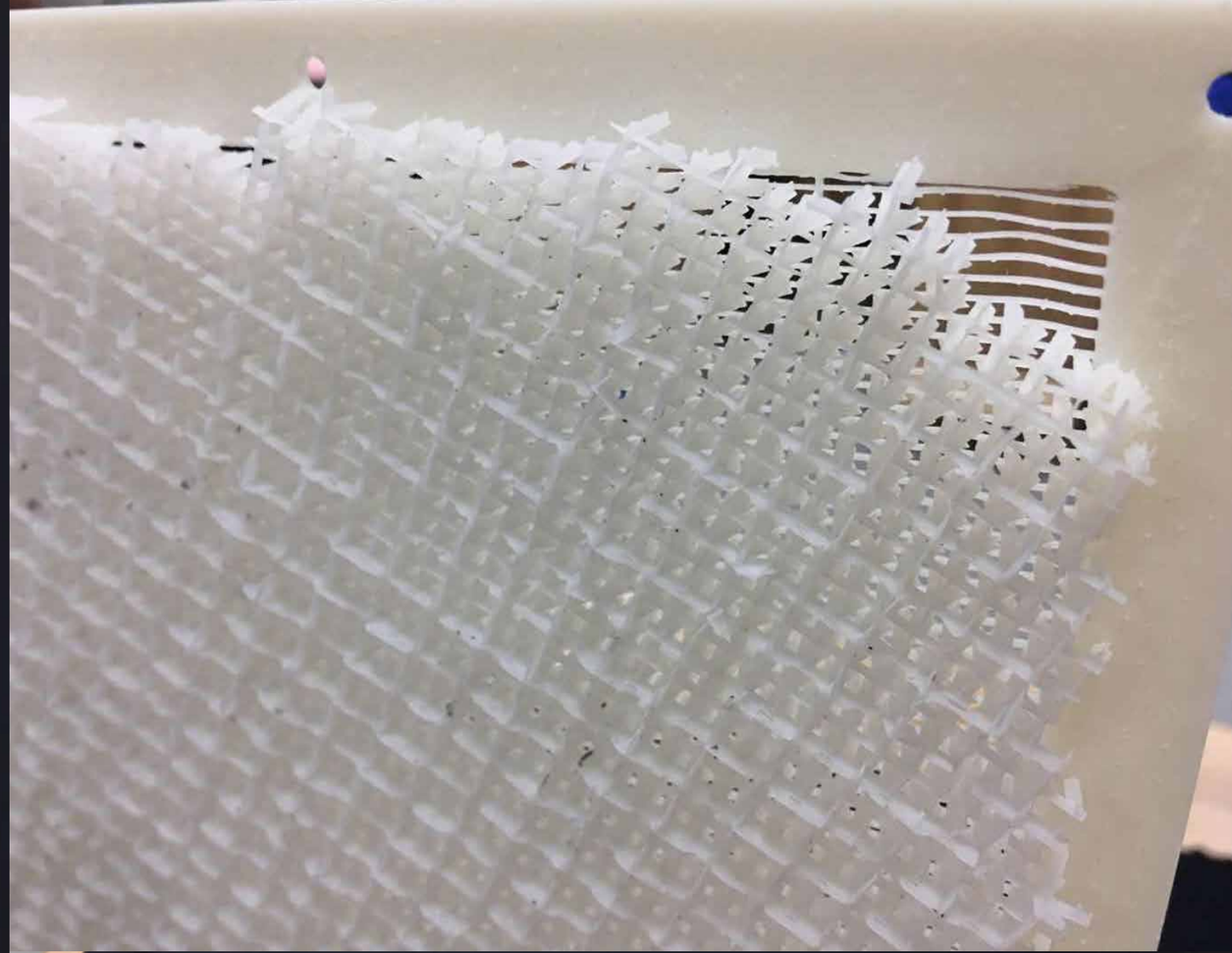
Craftcloud browser render detail



Our .stl file

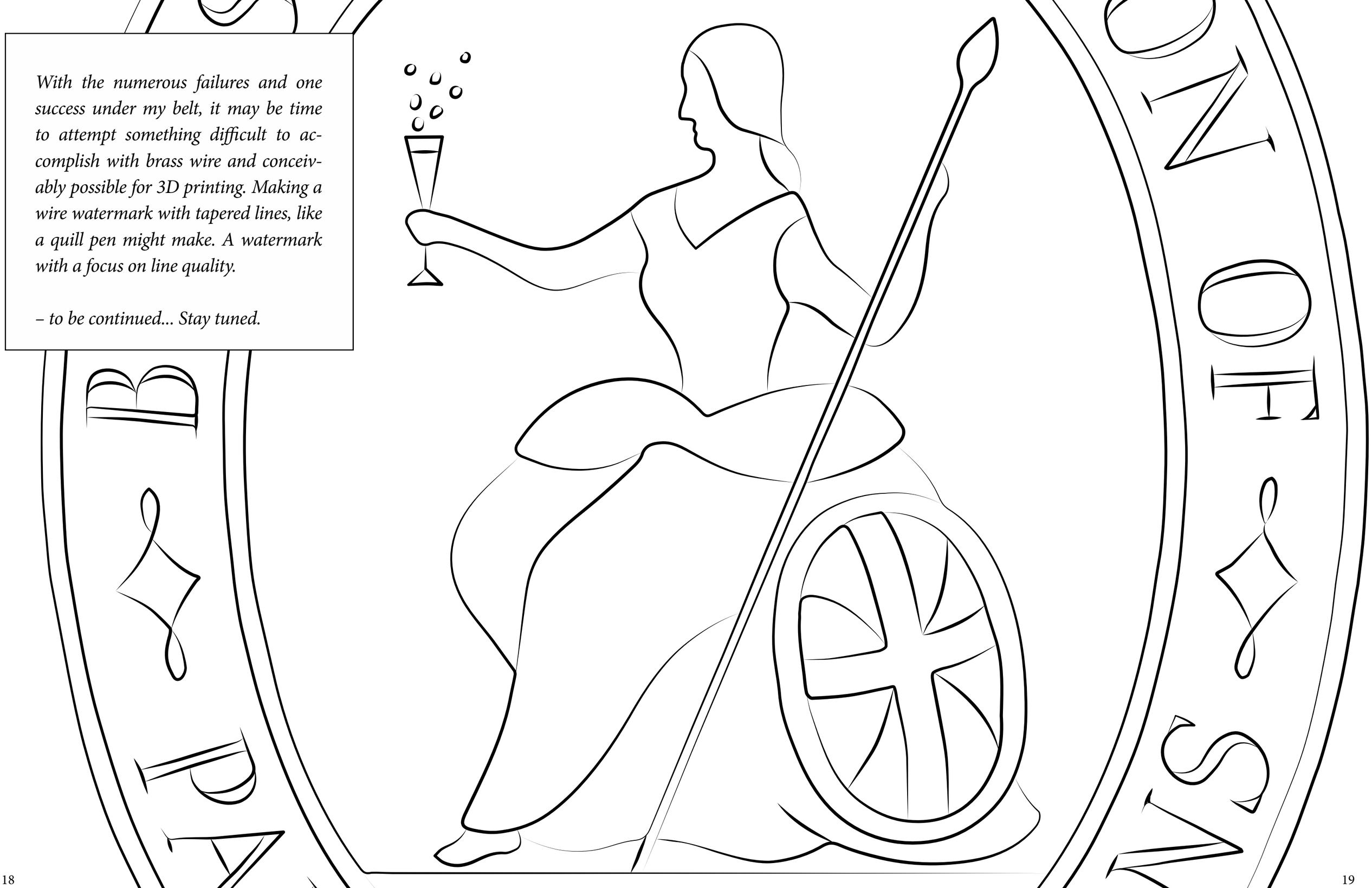
The results from China. Nobody said this was easy or, for that matter, even possible. This page of failures illustrate the current state of the technology. Or maybe the "scafolding" is the problem.

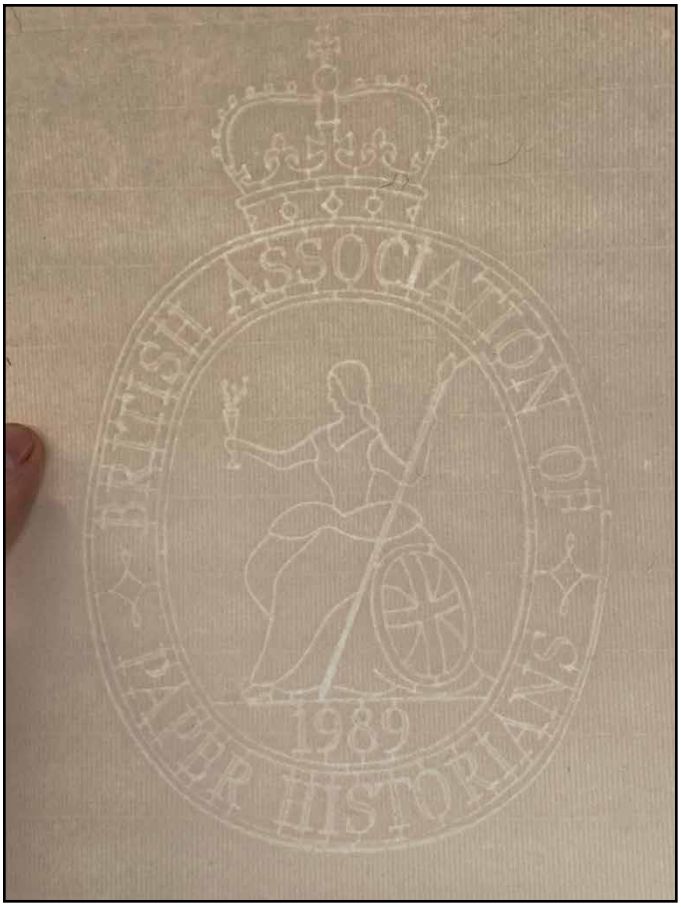


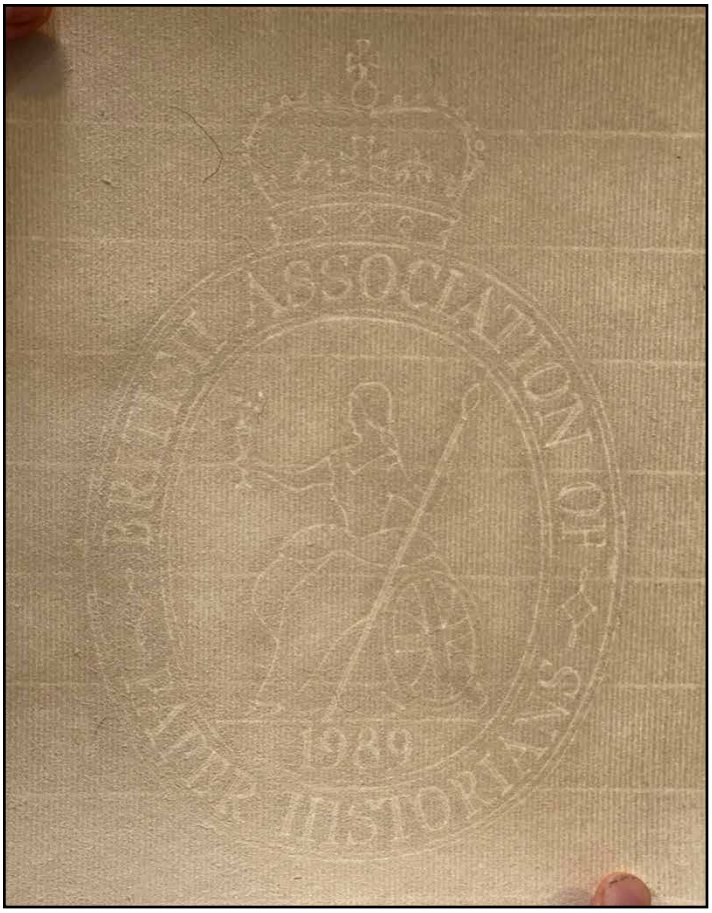


With the numerous failures and one success under my belt, it may be time to attempt something difficult to accomplish with brass wire and conceivably possible for 3D printing. Making a wire watermark with tapered lines, like a quill pen might make. A watermark with a focus on line quality.

– to be continued... Stay tuned.







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)