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Frank Cooper is a lifelong jewellery industry professional and a Senior Lecturer in Jewellery Manufacturing Technologies, and Manager of the Centre for Digital Design and Manufacturing, at the Birmingham School of Jewellery. He sits on the Goldsmiths' Craft and Design Council and is a globally recognised expert in the application of various Additive Manufacturing and prototyping/3D printing technologies used in the jewellery industry. He is an active participant in a number of Jewellery Industry related research initiatives and has written and presented many technical papers and articles published and presented around the world and in the UK and Europe, as well as at the Santa Fe Symposium in America. His research papers and presentations currently specialise in the areas of Additive Manufacturing, CAD and prototyping/3D Printing for the Jewellery and Silversmithing Industries.

With the recent ending of a number of patents, along with the burgeoning home 3D printing movement (e.g., Fab@Home, RepRap), a huge and often confusing number of new, low-cost 'home-user' or 'consumer-level' printers have arrived onto the 3D printing scene. A possibly useful spin off from this for the jewelry industry has been the emergence of a number of, principally but not exclusively, low-cost Digital Light Processing (DLP) systems. Many of these have been developed specifically for, or are capable of, printing in castable resins (photopolymers), which are ideal for use in the jewelry lost-wax investment casting process.

“Do the new low-cost 3D printers have a place in the jewelry manufacturing environment?”

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INTRODUCTION

LOW-COST 3D PRINTING SYSTEMS AND THEIR EMERGENCE

Terry Wohler’s, whose organization annually produces the Wohlers Report,6 is a well-known and widely reported ‘guru’ in the 3D printing world who in 2015 wrote the following:

“What do EmberSurge, 3D Evolution Printer, 3Dom, and 3Dponics have in common? And, Avatarium, Bondswell, Chemcubed, and Chimak3D? They are all start-up companies in the rapidly-growing 3D printing industry. Others include Cubibot, Dongguan Pioneertr, Fathom, 3D Filkemp, Growshapes, and HoneyPoint3D. The list just goes on and on. Have you heard of any of them? I had not, until recently. These small companies exhibited at last year’s Inside 3D Printing event in Santa Clara, California USA. The surge in start-ups is part of a seemingly endless sequence of such events in the 3D printing industry. It’s an indication that 3D printing has been, and continues to be, ripe for innovation. The excitement surrounding the technology and circulating information—coupled with a lot of hype—is leading to the introduction of many new ideas, companies, businesses, business models, and products. Will most of them survive and thrive?

History strongly suggests that they will not. A September 2014 article in Fortune7 states that nine out of 10 start-ups fail. Also, it’s important to note that many 3D printing companies have come and gone in the past. Even so, it’s encouraging to see so many entering the market. It shows that scores of entrepreneurs and investors are betting on it, even when the odds are stacked against them. Is this yet another sign that 3D printing will be an important part of our future?”8

IS DMD THE SAME AS DIGITAL LIGHT PROCESSING (DLP®) AND HOW DOES IT WORK?

The digital micro-mirror device (DMD) was invented by Dr Horbeck at Texas Instruments in 1987. Texas Instruments then registered DLP® as their trade name for the process and the DMD’s produced by them, and the acronym of DLP is now more commonly used than the generic name DMD which will be used in this paper. DMD printing is similar to stereolithography9 in that it is a well-established and mature 3D printing process that functions in conjunction with light cured photopolymers. The major difference between the two technologies is in the light source used to cure the photopolymeric resin. DMD uses a more conventional light source, such as an overhead projector bulb or, more recently, Light Emitting Diode (LED) bulbs whereas stereolithography uses various laser light sources. This light source in DMD is then selectively applied to the entire surface of the vat of photopolymer resin in a single pass, thus creating a ‘masking’ profile that cures the resin in a single pass or flash of light. Instead of using the heat generated from a light source to cure the resin, it uses a specific wavelength of light to activate the chemical reaction of the resin. Like stereolithography, DMD can produce extremely accurate parts with excellent resolution; it also imposes the same processing requirements for support structures and post-curing as stereolithography. However, one advantage of DMD is that only a shallow vat of resin is required to facilitate the process, which can generally result in less waste and lower running costs. The schematic in Figure 1 shows the typical mechanical layout for the DMD process.

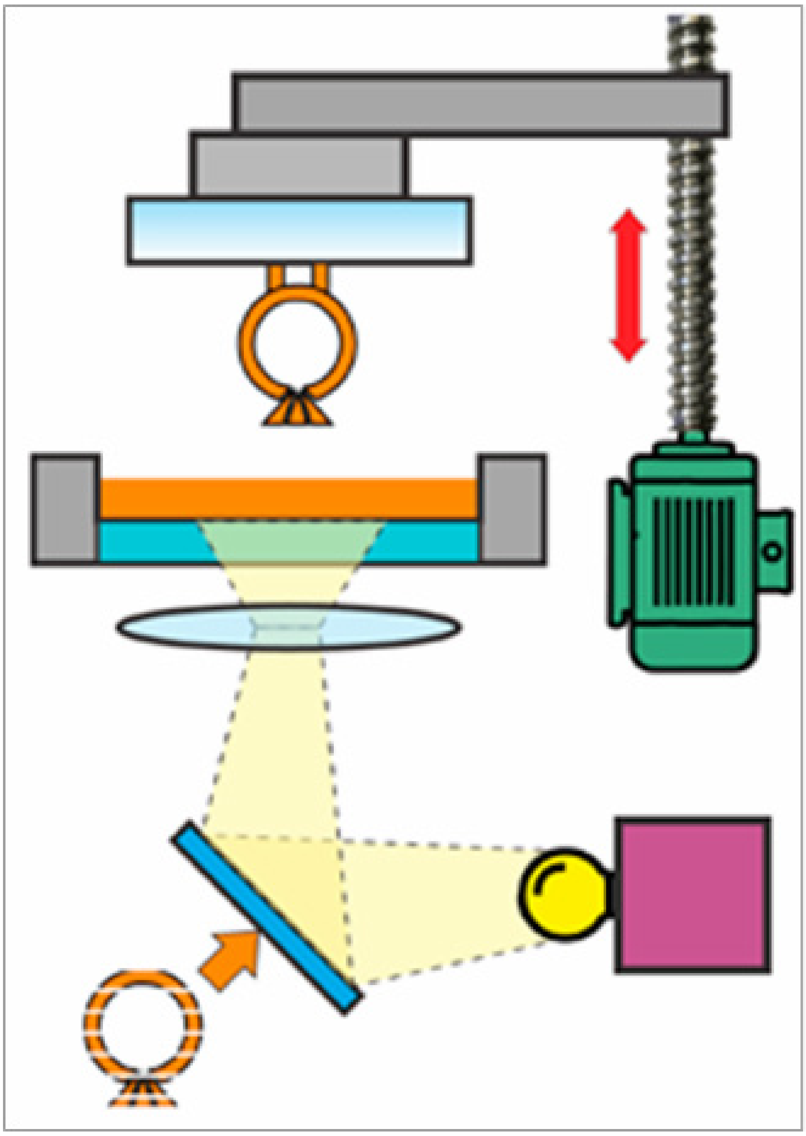

Figure 1 A schematic of the typical DLP process

There have been a large number of new, low-cost 3D printers released into the marketplace in recent years, many of which are suitable for or aimed at the jewelry market. They are making some impact on the jewelry industry but, as with any major capital-equipment purchase, you need to be very sure you do your homework before you buy in order to find out if it really is the right solution for your business needs. Not all desktop DMD printers are created equal and this paper aims to attempt to help you with that decision-making process.

Some of these printers employ a diamond-shaped pixel, possibly as a way of overcoming existing patents; however, for 3D printing, a square pixel is considered by many to be important in order to deliver high-resolution, crisp details on small jewellery-specific textures such as small settings and even micro pavé. 3D CAD programs as well as most digital imaging from televisions to computers rely on a square-shaped grid pattern of pixels. (A rough rule of thumb tends to be the more expensive a DMD technology is, the more likely it is to use a square-shaped grid pattern and a projector bulb.) Open up any photo on your computer and zoom in far enough to see the pixels. You will see that they are laid out in a square pattern. When transferring those pixels to a diamond pattern, adjustments need to be made by the software so that one square pixel is now located within multiple pixels instead. This conversion might in some cases leave jagged edges and/or inconsistent results. As you can see in Figure 2, something as simple as a straight line one pixel wide could result in a jagged line on a diamond pattern. A simple ring head with 90° angles might well prove to be challenging for the diamond pattern but should be precise and smooth on a square-pixel pattern. Even though we are talking at a pixel level, the finished model may not be as smooth from a diamond-pixel pattern, which could possibly lead to later casting problems caused by poor model quality and resolution fidelity.

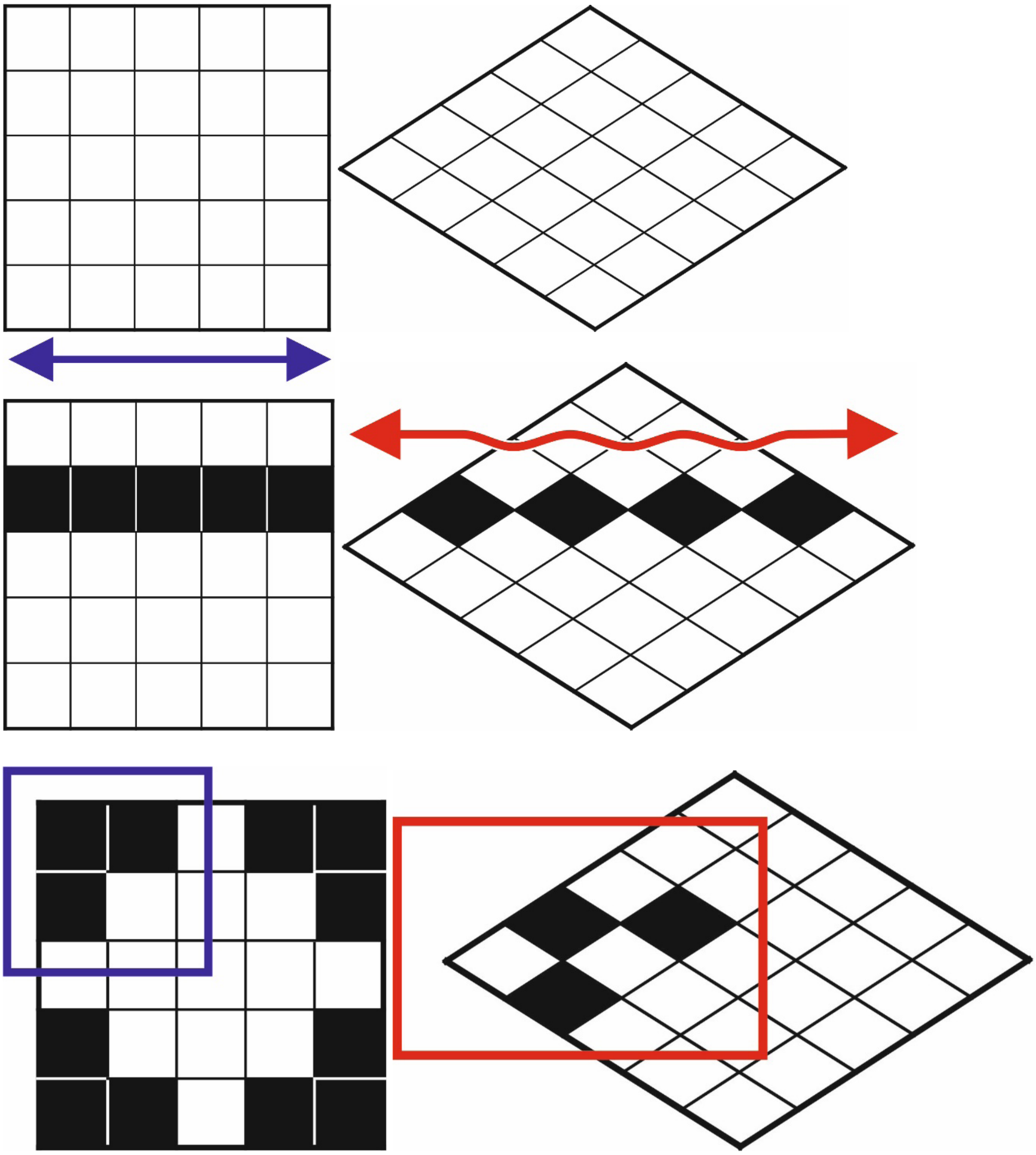

Figure 2 Square and diamond pixels

Single-pixel resolution that is focused evenly across the entire build envelope is the ideal to look for as this leads to not only a smoother surface finish but also consistency for each piece on the build plate. This consistency is at times not easily achieved with a 3D printer utilizing a diamond-pixel configuration due to the square-to-diamond conversion process, leaving not only the jagged outer edge problem but also a tendency towards 'blurring' the farther the piece is away from the center of the build area and the light source. This is why many of the newer generation of low-cost DMD printers tend towards quite low-surface-area build plates when compared to their more professional-level competitors.

Another cost-saving measure that contributes to the 'blurring' effect and worthy of being acknowledged here is the use of plastic optical lenses on some of these lower-priced 3D printers. Over a period of time, especially in the right climatic conditions, these plastic lenses can begin to distort, particularly if they are not designed specifically for use with a light source at the wavelength needed to cure the photopolymer being processed. These lenses may eventually begin to fog after prolonged exposure to a particular wavelength of light. As the fogging and distortion increases, inconsistency in builds may begin to appear with parts of the model possibly not fully curing. If at all possible, you should attempt to seek out printers that incorporate an industrial-grade glass lens that is optimized for the precise wavelength of the LED light source in the printer's projector. The photopolymers developed for use with the printer should also be optimised for the wavelength of the light transmitted through the glass. This optimisation of optics, light-source wavelength and resin, when correctly balanced, needs to deliver high-quality detail down to near single pixel resolution that is consistent over the entire build area.

The hardware and materials used in these printers are not the only areas where attention to the small details is important. Good-quality 3D printing requires models with a closed or 'water-tight' geometry. This means the wire mesh of the CAD design must be

closed without any folded surfaces, gaps or duplicated lines or surfaces. When preparing a file to be 3D printed, the model must also be supported strategically within the build so that nothing sags or breaks off during the build process. All the printers come with their own integral and specifically developed support creation software. (Support creation for these technologies is certainly worthy of a research paper of its own.) Then, additional software is also required to verify the CAD file; finding and repairing any errors is essential to the building/printing of a successful finished product. At the School of Jewellery we encourage our students to use the free download of Netfabb Basic,10 which does exactly as it says on the box — a basic but okay job of verification and repair.
There has been considerable excellent research done and reported at past Santa Fe Symposia about both the use of suitable CAD files and data and the use of photopolymers/resins for printing castable patterns for jewelry use. To those who have not already done so, I would recommend as essential reading the following research papers to be found on the new and excellent Santa Fe Symposium® archive site that carries all the papers published at the Symposium.11
"Designing for Rapid Manufacturing and Other Emerging Technologies"12
"CAD Software for Jewelry Design: A Comprehensive Survey"13
"Digital Design Best Practices"14
"Direct Casting Photopolymer Resin Models"15
"Quality Excellence in the Direct Casting of RP Resins: Reality or Fiction?"16
"Improvements in the Burnout of Resin Patterns"17

Many of the low cost consumer-level 3D printers carry only a limited warranty and little to no technical support other than online, so again it is well worth assessing your own organization's technical ability and nous when it comes to being your own 'tech guy' with these technologies. The jewelry industry is now relying more and more heavily on advanced manufacturing technologies like 3D printing to help their businesses thrive and grow. Jewellery designers and manufacturers who wish to remain competitive by investing in one of the 3D printing solutions have many options at a variety of price points to consider, so my colleagues and I suggest, when asked, that when it comes to your business and ultimately your reputation, make sure to research these options very thoroughly so that a good and accurate decision can be made about the operational features and quality of outputs you will require. I would recommend that you do not base your decision solely on the cost!

THE RESEARCH METHOD AND PROCESS ADOPTED

It is a pre-requisite of my university's Art, Design and Media faculty research office that certain key research questions must be posed, answered and reported in our research. It is this philosophy that has determined the research processes and methods of reporting that have been chosen and reported on for this particular research project.

This process was the subject of much debate amongst my team. I shall cover some of that debate here, starting with the research philosophy to be adopted, which needed to allow for the subjective nature of the proposed observations to be made. The reasons for choosing this particular approach will become clearer when we consider the nature of the 'tools' we chose to adopt for making those observations. The observations themselves will be based on our own jewellery industry-based experiences and knowledge and what in our understanding constitutes a good- quality print that eventually results in an acceptable casting specifically for use within the jewelry manufacturing industry. We are required by the university's research office to use the following definition for our subjective research into what are considered to be artisanal or art and craft subjects of which jewellery design and manufacture is one.

"Subjective, otherwise known as qualitative, data is derived mainly through sensory observations and overall impressions of a particular phenomenon. It necessitates a researcher to count themselves as one of the measuring instruments in that his or her perspective will be colored by experience, perception, bias, and personal meaning attributed to events observed. This method of collecting data is seen in field observations, unstructured subject interviews, and narrative investigation. This research methodology tends to decrease the statistical significance of the data but lends a deeper more nuanced understanding to what is under study."

Although more scientific and advanced technologies could have been accessed and used for data capture in this particular study, it was determined that we would attempt to keep it to tools and equipment familiar to, or reasonably easily accessed by, the smaller workshop jewelry manufacturer because the printing technologies being studied are aimed at these self-same smaller workshops.

OBSERVATIONAL TOOLS USED FOR THE STUDY

1. The "mark 1" human eyeball (connected to a supercomputer called the brain!)
2. The loupe or Optivisor
3. Microscope
4. Camera plus macro lens (with suitable light box)

The most-used instrument for this study after direct visual observation and interpretation was our Breukhoven Digital Stereomicroscope, which offered not only a magnification range from 10X to 40X but also gives us the option to digitally capture the image shown on the tablet screen. However, as a rule of thumb we adopted a process where we only used the microscope and camera to confirm what we felt we could observe either with the naked eye or loupe/ Optivisor magnification.

Figure 3 Our digital stereomicroscope

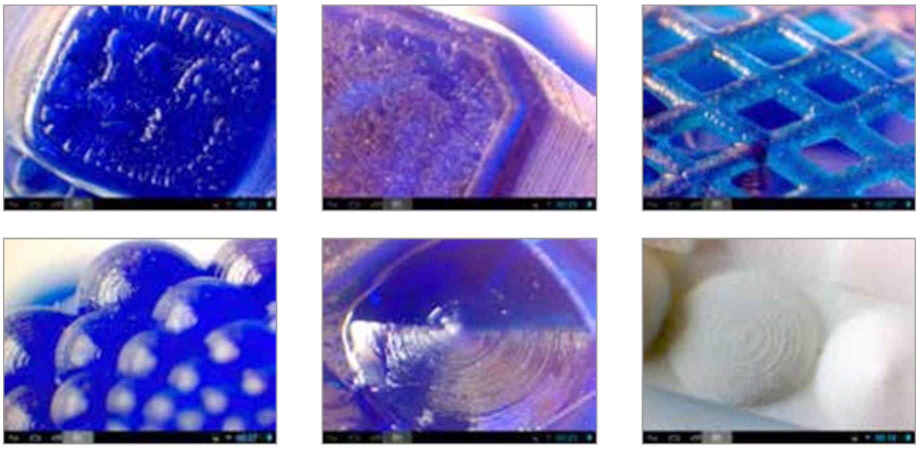

Figure 4 Some examples of the images of prints captured by the microscope

Above are a selection of images captured by the microscope and used to confirm our own visual observations about the build lines that are an inevitable consequence of using an additive layer manufacturing build/print process.

PRINTING TECHNOLOGIES USED FOR THE STUDY

Ember Printer

Figure 5 An Ember printer

ProJet 1200

Figure 6 A ProJet 1200 printer

Form 2

Figure 7 A Form 2 printer

The Form 2, as shown in figure 7 above, is probably less well known in the jewelry industry but is gaining considerable traction in other 3D Printing spheres and will almost certainly breakthrough into the jewelry industry in a major way soon. The Form 2 uses stereolithography (SLA) technology (as opposed to being a DMD technology) and uses an integrated resin system and sealed optics which are described as relatively easy to maintain and operate. The Form 2 also offers wireless connectivity for print uploading and job queuing. Different 3D printer manufacturers will often use different metrics to define “resolution”, but layer thickness is one commonly cited standard. This technology can print in layers as thin as 25 microns. Minimum feature size, on the other hand, refers to the thinnest wall or finest point, which can be as small as 300 microns. The Form 2’s laser beam can move in steps of fewer than 10 microns, creating precise movements and what we found to be an impressively smooth surface finish.

Test Prints

The next question to be addressed was that of what precisely should we print and research. We began by analyzing what we, as jewelers, look for in a print that we intend to send through the casting process (as opposed to a print intended to be used as a master pattern in a mold). This was quite quickly broken down into some explicit areas that were by their nature very jewelry-specific and are listed here in no particular order of importance or preference.

1. Curved surfaces as found in ring shanks
2. Curved surfaces other than ring shanks, effectively spherical-type structures
3. Flat surfaces as often found on signet rings
4. Prongs of varying diameters that are used to set stones
5. Flat, vertical, walls of varying thicknesses as often used on rub-over (bezel) settings
6. Lettering and numerals, both raised and inverted/sunken as found on class rings
7. Concave and convex surfaces as found in nature (leaves and petals)
8. Mesh or filigree surfaces

So we set to creating numerous sketches, CAD drawings and files of various items of jewelry that exhibited some or multiples/mixtures of the various desired geometries until one of the team pointed out that we were about to generate vast quantities of CAD files, 3D prints and eventually castings. The simple math was that we had around 20 different jewelry items that we were proposing to print on three different technologies, which was going to result in 60 prints to be built, assessed, recorded and cast, and assessed and recorded again. We were looking at the beginnings of a very large spread of data and images. We then also had to factor in that on one of the technologies, we intended to attempt to process up to three different photopolymers! We were now into the region of 100 test pieces to be processed. We were also considering printing a batch of ‘control samples’ on a more high-end printing system such as a Solidscape® and/or EnvisionTEC©. We were now looking at approaching 150 test pieces. But it didn’t end there as word spread amongst the various technology vendors (admittedly, I was telling them about our research proposal when I met them at various shows, conferences and seminars). We started to get requests from other vendors to add their technology’s output to our research results/database. This was quickly growing into a bit of a monster of a research project of near frightening proportions, so we stopped to reassess the situation and to look for more equitable solutions to the volume of data being generated.

The first major decision was that for the purposes of the specific research project, we would maintain using only the originally proposed three different technologies, including running the different polymers on one of them. However, we have decided to attempt to continue the research project beyond this smaller scope in order to try to develop in the future a database of results that is as comprehensive as possible. As with all university research here in the U.K., this will be subject to us finding suitable research funding for such a project.

We also had an idea to try and combine as many of the geometries we wished to test and examine into a single piece or block. Although this would no longer be recognizable as a piece of jewelry, many of the forms, shapes and geometries listed earlier would be evident and present in a piece that came to be known as ‘the block’ (Figure 8). At this point I would like to acknowledge Paul Yeomans, the member of my team who did all the CAD work and many of the builds, and thank him for his diligent attention to detail. He is one of our CAD engineers and technicians who also operates the printing technologies

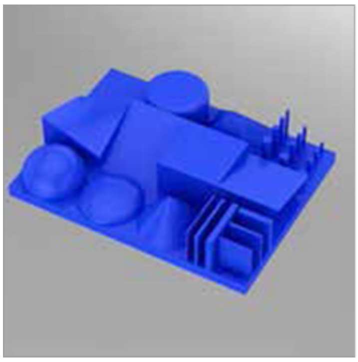

Figure 8 The block

The block has within it 12 columns/prongs ranging from 0.50 mm to 1.50 mm diameter of varying heights. They are arranged in a grid pattern to allow for two directions of movement in those printing technologies that might have a moving or sweeping action. The prongs are meant to represent various sizes of setting prongs. Similarly, the flat-wall sections range from 0.25 mm to 1.00 mm and are also arranged to allow for any sweeping actions involved. They could be considered to represent various rub-over (bezel) settings.

For assessment purposes the block was divided into its 12 component parts as seen in Figure 9. From left to right and top to bottom: Area 1 is the flat surface, area 2 is the vertical cylinder, area 3 is the pyramid, area 4 is the grid of columns, area 5 is the concave/convex surface, area 6 is the 45° slope, area 7 is the cube, area 8 is the double-inverted slopes, area 9 is the high dome, area 10 is the low dome, area 11 is the inverted cone and area 12 are the flat-wall sections.

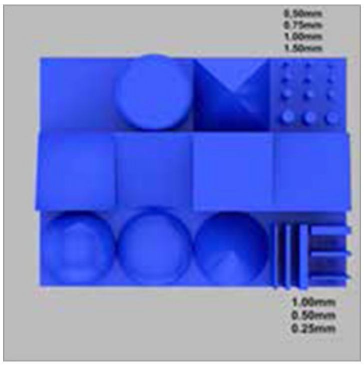

Figure 9 The block viewed from overhead

We decided that we still had a number of geometries and shapes we needed to research that did retain the original jewelry product design intent so we would still have some atypical ring forms to examine and relate to. The first two rings (Figure 10) also incorporate indented and raised lettering with curved shoulders and a half-round shank reminiscent of a typical signet ring form. We chose our university logo and name to create the desired lettering and form.

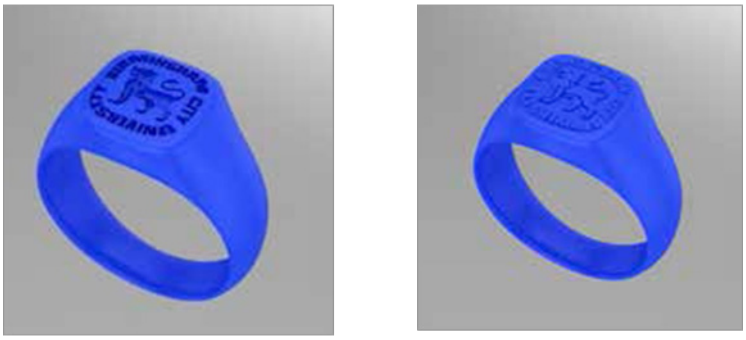

Figure 10 The BCU class rings, indented lettering (left) and raised lettering (right)

Next we included a tried and trusted design with whom some of you may be familiar—a filigree or mesh-like ring that has been used by us a number of times before in various trials, tests and research projects and is usually described as a cage ring. Not only is it a predominately mesh structure, it also curves in a number of divergent directions.

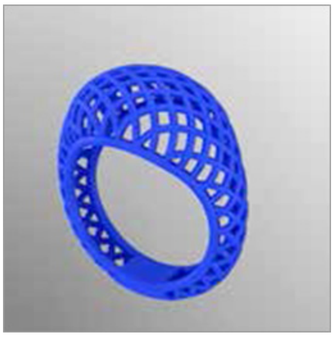

Figure 11 The cage ring

Finally, we also included a ring that for some reason became known as the Pavlova ring’. This ring includes not only a more half-round section shank than the class rings, but it also includes a number of spheres of varying and reducing sizes assembled in a tapering cone-like structure, which it was agreed would be a good test of print quality and build resolution.

Figure 12 The Pavlova ring

Next we had to consider our logging, control and information-collection process as we hoped to record not only which technology was used but also what was printed, in which polymer, additional possibly pertinent information such as what CAD program was used for the design and any automatic or manually placed supports used. Finally, we needed to record the parameter settings that were used, wherever available. To this end the recording sheet in Figure 13 was created. A small selection of the large mass of samples and paperwork being collated is also shown.

Macchina

Machine		Ember EnvisionTec EOS Mo80 Objet 30 ProJet 1200 ProJet 3500 CPX MAX Solidscape 3Z
Item	Pavlova Signet +/-	Cage Ring Plate
Material		
Slice Thickness µ		
Date		
Notes		
Photos		

Figure 13 Data collection and collation

We formed a review panel to carry out a blind subjective analysis of the build and cast parts of this research where the panel was asked to consider their view on the quality and 'usability' of each print and any resultant castings. This was done by use of a paper-based voting system in the form of a secret ballot with the reported result being carried by a simple majority. The panel consisted of School of Jewellery staff members and included a CAD and 3D print specialist, a bench jeweler/tutor, a casting specialist and a designer. I had the final casting vote.

We set ourselves the following simple criteria for reviewing the prints and castings:

In your view is this print 1) of excellent quality, 2) of acceptable quality, or 3) of unacceptable quality?
In your view is this casting 1) of excellent quality, 2) of acceptable quality, or 3) of unacceptable quality?
Finally, we needed to decide on a manageable and understandable way of recording and presenting the results so the following tables were created. As a rule of thumb we discovered that what was subjectively considered to be a poor print/build surface invariably resulted in what was deemed to be a poor casting. However, it should be noted that the description of 'poor casting' actually applies more to the surface finish and quality of the print than what we might consider to be more traditional casting defects such as porosity.

The results in Tables 1-4 attempt to accurately reflect the combined subjective views of the panel about both the build and cast quality.

Table 1 Subjective review of the panel on results from an Ember 3D printer using Ember Castable

Item	Technology	Material	Excellent Quality	Acceptable Quality	Unacceptable Quality
Area 1	Ember	Ember Castable			✓
Area 2	Ember	Ember Castable		✓	
Area 3	Ember	Ember Castable		✓	
Area 4	Ember	Ember Castable	✓		
Area 5	Ember	Ember Castable		✓	
Area 6	Ember	Ember Castable		✓	
Area 7	Ember	Ember Castable	✓		
Area 8	Ember	Ember Castable	✓		
Area 9	Ember	Ember Castable		✓	
Area 10	Ember	Ember Castable			✓
Area 11	Ember	Ember Castable	✓		
Area 12	Ember	Ember Castable	✓		
Class ring indented	Ember	Ember Castable		✓	
Class ring raised	Ember	Ember Castable			✓
Cage ring	Ember	Ember Castable	✓		
Pavlova ring	Ember	Ember Castable	✓		

Table 2 Subjective review of panel on results from an Ember 3D printer using DWS resin

Item	Technology	Material	Excellent Quality	Acceptable Quality	Unacceptable Quality
Area 1	Ember	DWS Resin		✓	
Area 2	Ember	DWS Resin	✓		
Area 3	Ember	DWS Resin	✓		
Area 4	Ember	DWS Resin	✓		
Area 5	Ember	DWS Resin	✓		
Area 6	Ember	DWS Resin	✓		
Area 7	Ember	DWS Resin	✓		
Area 8	Ember	DWS Resin	✓		
Area 9	Ember	DWS Resin	✓		
Area 10	Ember	DWS Resin	✓		
Area 11	Ember	DWS Resin	✓		
Area 12	Ember	DWS Resin	✓		
Class ring indented	Ember	DWS Resin	✓		
Class ring raised	Ember	DWS Resin			✓
Cage ring	Ember	DWS Resin	✓		
Pavlova ring	Ember	DWS Resin	✓		

Table 3 Subjective review of the panel on results from a Form 2 3D printer using Form 2 Castable

Item	Technology	Material	Excellent Quality	Acceptable Quality	Unacceptable Quality
Area 1	Form 2	Form 2 castable			✓
Area 2	Form 2	Form 2 castable	✓		
Area 3	Form 2	Form 2 castable	✓		
Area 4	Form 2	Form 2 castable	✓		
Area 5	Form 2	Form 2 castable		✓	
Area 6	Form 2	Form 2 castable		✓	
Area 7	Form 2	Form 2 castable		✓	
Area 8	Form 2	Form 2 castable			✓
Area 9	Form 2	Form 2 castable	✓		
Area 10	Form 2	Form 2 castable		✓	
Area 11	Form 2	Form 2 castable	✓		
Area 12	Form 2	Form 2 castable	✓		
Class ring indented	Form 2	Form 2 castable		✓	
Class ring raised	Form 2	Form 2 castable			✓
Cage ring	Form 2	Form 2 castable			✓
Pavlova ring	Form 2	Form 2 castable	✓		

Table 4 Subjective review of the panel on results from a Projet 1200 3D printer using VisiJet® FTX Cast

Item	Technology	Material	Excellent Quality	Acceptable Quality	Unacceptable Quality
Area 1	Projet 1200	VisiJet® FTX Cast			✓
Area 2	Projet 1200	VisiJet® FTX Cast		✓	
Area 3	Projet 1200	VisiJet® FTX Cast		✓	
Area 4	Projet 1200	VisiJet® FTX Cast			✓
Area 5	Projet 1200	VisiJet® FTX Cast			✓
Area 6	Projet 1200	VisiJet® FTX Cast		✓	
Area 7	Projet 1200	VisiJet® FTX Cast	✓		
Area 8	Projet 1200	VisiJet® FTX Cast			✓
Area 9	Projet 1200	VisiJet® FTX Cast		✓	
Area 10	Projet 1200	VisiJet® FTX Cast		✓	
Area 11	Projet 1200	VisiJet® FTX Cast		✓	
Area 12	Projet 1200	VisiJet® FTX Cast			✓
Class ring indented	Projet 1200	VisiJet® FTX Cast		✓	
Class ring raised	Projet 1200	VisiJet® FTX Cast			✓
Cage ring	Projet 1200	VisiJet® FTX Cast		✓	
Pavlova ring	Projet 1200	VisiJet® FTX Cast		✓	

Note: In all cases and examples charted above, the class ring with raised letters was considered to be of unacceptable quality, but it is also accepted here that the problem lies primarily with the original CAD file rather than the ability of any of the printing technologies to reproduce the file adequately.

CONCLUSIONS

While this is clearly a body of ongoing and unfinished research, there are a number of conclusions that can be considered of interest to us as jewellers.

There is a considerable gap, often in the region of tens of thousands of Euro's, Dollar's or Pound's between some of the more well-known and mainstream 3D printing technologies and their less expensive rivals as exampled here. However, while acknowledging that there is a gap in the quality of the output between these 'high-end' and 'low-end' technologies, it is a much smaller gap than the relative purchase price differentials would appear to indicate would be the case.

In our view a key factor is the willingness and ability of the bench jeweller that is considering adding one of these technologies to their workshop to work with the output as they would with an occasionally wayward casting produced using more traditional or well-known processes. Sometimes the output will be less than perfect but if you are willing and able to do just a few more minutes filing and buffing of the resultant casting, then you have the possibility of bringing another stage of the manufacturing process much more under your direct control from both a cost and quality viewpoint.

Adding a suitably cost-effective 3D printer to your workshop's toolbox will bring with it a number of factors that will need serious thought and consideration. As stated earlier, the output from any 3D printer is only ever going to be as good as the CAD input used. The old adage still stands: "Rubbish in equals rubbish out." Who is going to learn and develop those CAD skills within your organization or company? Learning CAD isn't quick or easy and requires constant practice and repetition. Will you or one of your employees have the time to learn and apply these skills, or do you need to look for a suitably skilled addition to your team? There is little doubt that the younger generation coming out of our schools, colleges and universities is far more computer literate and tech savvy than our current generation, but even they will need to be taught to understand at least the basics of how many aspects of jewellery manufacturing works in order to be able to create suitable CAD files.

Then you will need to consider which printer best suits not only your wallet and ability to supply suitable files but which will give you consistent and repeatable results through your own manufacturing processes. Just like any other capital equipment purchasing decision, be very sure to consider all the possibilities and options open to you and your business. If at all possible get test files built that reflect your typical product range and type. Don't just look at and consider the print output; get it cast and make sure it is compatible with your casting processes. Then finish it to make sure the final result is what you hoped for, expected and need.

For obtaining ongoing positive results, developing a working knowledge and understanding the physical and thermal properties of the photopolymer used in your technology of choice is also going to be key. Especially when these are combined with the occasionally variable parameters of the casting process, obtaining optimized and consistent results from both is going to be very important. This is why the options offered by the Ember system are worthy of serious consideration because this is an 'open source' system where you as the purchaser are not only free but actively encouraged to experiment with parameter settings. You can use any photopolymer you can obtain, and they even publish the recipe of their own castable photopolymer with the clear implication that you can remix it in differing ratios or add and subtract your own chemicals and binders. To do this you need to be an able and confident tinkerer or hacker but if you feel confident, then we would certainly recommend it as a viable option. You will see from the tables above that we chose to trial a photopolymer resin developed for a completely different technology (DWS 3D Printing Technology18) and which uses a solid-state blue laser. After some trial and error a set of suitable parameters was found, and the results were consistently the best of the four photopolymers we tested.

Ultimately, the decision remains yours but if you are seriously considering adding the world of entry-level photopolymer printing to your workshop, then we hope this paper has gone some way towards giving you some pointers and indicators to at least some of your options going forward.

REFERENCES

https://en.wikipedia.org/wiki/Fab@Home.
https://en.wikipedia.org/wiki/RepRap_Project.
https://en.wikipedia.org/wiki/Digital_Light_Processing.
http://www.ti.com/lsds/ti/dlp-technology/about-dlp-technology/how- dlp-technology-works.page.
R. Liska et al., “Photopolymers for rapid prototyping,” Journal of Coatings Technology and Research 4, no. 4 (December 2007): 505-510.
https://www.wohlersassociates.com/2015report.htm.
http://fortune.com/2014/09/25/why-startups-fail-according-to-their- founders/.
http://wohlersassociates.com/blog/2015/10/3e-printing-startups/.
https://en.wikipedia.org/wiki/Stereolithography.
http://www.netfabb.com/basic.php.
http://www.santafesymposium.org/papers/.
Gay Penfold, “Designing for Rapid Manufacturing and Other Emerging Technologies,” The Santa Fe Symposium on Jewelry Manufacturing Technology 2008, ed. E. Bell (Albuquerque: Met-Chem Research, 2008): 243-256.
Scott Patrick, “CAD Software for Jewelry Design: A Comprehensive Survey,” The Santa Fe Symposium on Jewelry Manufacturing Technology 2005, ed. E. Bell (Albuquerque: Met-Chem Research, 2005): 409-422.
Annie Koenig, “Digital Design Best Practices,” The Santa Fe Symposium on Jewelry Manufacturing Technology 2015, ed. E. Bell et al. (Albuquerque: Met- Chem Research, 2015): 181-212.
ary Dawson and Joseph Tunick Strauss, “Direct Casting Photopolymer Resin Models,” The Santa Fe Symposium on Jewelry Manufacturing Technology 2013, ed. E. Bell and J. Haldeman (Albuquerque: Met-Chem Research, 2013): 155-168.
Marco Actis Grande et al., “Quality Excellence in the Direct Casting of RP Resins: Reality or Fiction?” The Santa Fe Symposium on Jewelry Manufacturing Technology 2011, ed. E. Bell (Albuquerque: Met-Chem Research, 2011): 1-36.
Ian McKeer, “Improvements in the Burnout of Resin Patterns,” The Santa Fe Symposium on Jewelry Manufacturing Technology 2007, ed. E. Bell (Albuquerque: Met-Chem Research, 2007): 397-420.
http://www.dwssystems.com/.