Using acetone (propanone) as a post-production finishing technique: Crossing the divide between art and technology

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***Abstract*—Entry-level Fused Deposition Modelling (ELFDM) is an ever-expanding technology being utilized in the art and design industries. As this level of additive manufacturing technology suggests, there are limitations to the production outcomes and quality of end products. A need exists to improve post-production finishing techniques that will assist with reducing limitations and enhance aesthetic value. This brings about a debate around the production quality and value of 3D printed artefacts. Acetone (propanone) has been identified in a conclusive study as a promising substance to assist with the post-production finishing of ELFDM artefacts. The paper presents investigations from a qualitative and quantitative perspective to demonstrate acetone's impact on the aesthetic value and quality of artistic artefacts in the South African and international spheres. It demonstrates the influence of acetone on the tensile strength of ABS plastic, as well as the overall increased aesthetic value output of ELFDM produced artefacts. Further recommendations for future examination are also suggested to fast-track the development of this crucial component of the global art and design industries.**

Keywords and phrases: Entry-level Fused Deposition Modelling (ELFDM); Additive manufacturing (AM); Post-production finishing techniques (PPFTs); Aesthetic value; 3D printed artefacts; Acetone; Tensile strength; Ductility; 3D printed; prosumer; Selective laser sintering (SLS)

1. INTRODUCTION

The establishment and integration of 3D printing (3DP) in design, manufacturing and the arts can clearly be observed by the large number of online documented artists, makers and designers in industry. Unfortunately, the use of 3DP in industry is often restricted to high-end additive manufacturing. Entry-level fused deposition modelling (ELFDM) is usually excluded due to limitations such as time-consuming post-processing, build size restrictions and poor surface quality. This seems to indicate a reluctance to integrate ELFDM in the design and art markets and to stop it from being used for end production purposes.

The existence of post-production finishing techniques (PPFTs) can be found in makerspaces, when it is observed through online blog sites, which seems to show attempts to deal with ELFDM problems. These home-made experiments identify various techniques that point to a surface-finishing application in different aspects of art and design. However, no formal documentation system or academic guidelines have been developed for a recognized training module. Such PPFTs could provide industry with new 3DP options, furthermore it will broaden the spectrum of 3D printing users as entry-level prosumers will be able to afford this technology.

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In the fine arts, entry-level 3D printing (EL3DP) limitations and results that deviate from the original input or design, can be overlooked or integrated into the piece in some way, but the design world is less forgiving. Where corrective measures need to be taken, PPFTs can address limitations experienced with ELFDM.

This paper proposes to introduce PPFT solutions, including acetone application, to enhance surface finish, address exorbitant lead times and overcome build size restrictions for entry-level 3D printers. In doing so it could assist with narrowing the gap between technology and art, which will lead to the establishment of a niche market.

2 BACKGROUND TO STUDY AND LIMITATIONS (LITERATURE STUDY)

- **Background of FDM and its place in additive manufacturing.**

Additive manufacturing (AM) is the automatic layered fabrication of physical objects directly from computer-aided design (CAD) data. These technologies are also being increasingly used in non-prototyping applications; thus, the techniques are frequently referred to as computer automated manufacturing or layered manufacturing [1]. These systems add and bond materials in layers to form objects. With these additive technologies, an object can be formed with high geometric complexity or intricacy without the need for elaborate machine setup or final assembly [2]. Robert Olson says that 3D printers are most commonly used in additive manufacturing for the high-end industry to create ‘final products’ [3].

Any specific production technique has a noteworthy influence on the productivity, cost and quality aspects of artefacts. Such traditional methods used by artisans, designers and engineers alike can be seen as outdated, time-consuming and inefficient. These sub-standard techniques have considerably affected the productivity and quality of output products, that invariably lead to unsuccessful or unsustainable enterprises [4].

Research shows that the integration of AM technology in the product lifecycle can reduce the time and cost of normal production parameters significantly by up to 10-50% [5]. As illustrated in Fig. 1, when rapid prototyping technology is integrated into the product lifecycle, the assembling and function testing can be done simultaneously during manufacturing. This is due to the ability of AM technology to integrate multiple operations in manufacturing, which saves time and production cost.

AM usage, reduces the time and cost of artefact production in general, when compared to previous technologies like injection moulding and composites.

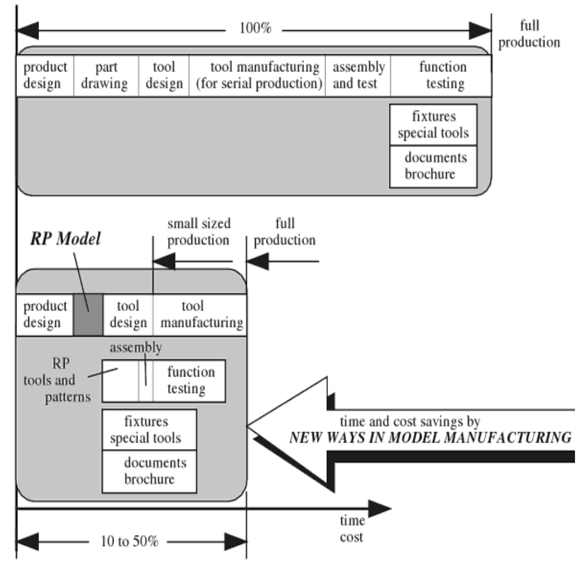


Figure 1 Results of integration of Rapid Prototyping Technology [5]

However, it is still an extremely costly process for people like artists, who only have limited access to production funding. Most artists cannot afford the costly production methods of high-end additive manufacturing. This makes the use of laser sintering, for example, almost impossible for the mainstream artist as will be indicated by the qualitative research and literature study later in this paper. When we refer back to Fig. 1 above, it clearly identifies a lack of recognising the place or need of a post-processing phase in AM production lines. To resolve high cost implications, prosumers should look towards entry-level production methods; however, to do that, the limitations of the entry-level technology should first be addressed.

Solving limitations such as cost factors could drastically increase the number of users utilizing the technology, not only opening the possibility to narrow the gap between high-end and entry-level production but also leading to development in the technology.

- **FDM usage in art and design; and its relation to AM. Accidental occurrence vs. precise design. ART vs. design/engineering**

Several researchers indicate that an important factor for unsuccessful artistic endeavours is obsolete designs of or for end products [4, 6 and 7]. Poorly finished artefacts that were produced on (EL3DP) will therefore discourage consumer interest. Two reasons are mainly creating this effect. Firstly, the above-mentioned lack of developing PPFTs for the entry-level market and, secondly, the opinion of the consumer is not considered. For the most part, the prosumer determines the meaning and function of artefacts produced through 3D printing. If consumer 'wants' are neglected, this will create confusion about aesthetic value output. This seems to blur the lines between the acceptable and unacceptable when ELFDM is under discussion.

In art, the 'modernist' concept identifies the creator (artist, craftsman or designer) as the sole creative agent. This person also determines what to produce and how to produce it. However, in 'postmodernism' this idea is overturned and suggests that the consumer is also an important creative agent in deciding the value of artefacts. For example, it is believed that if we are building artefacts for the benefit of people (users), then the knowledge of the consumer is required (user centred) just as the creative skills of the prosumer (creator) are needed.

To arrive at a better understanding of how the consumer, prosumer and artefact interact we can look at the research of Paul Hekkert and Hendrik Schifferstein, *Product Aesthetics in Product Experience.* Giving a better understanding of the theory of artefact experience, it is described as "our subjective understanding of the properties of an object through sensory interaction" [8]. Therefore, when we approach the aesthetic quality debate of an artefact, it can be seen that art ideology blurs the definitions set by design about what a successfully completed artefact might be.

Krippendorff and Butter define product semantics as the study of the context and symbolic qualities of a product through the application of Industrial Design. Through an understanding of product semantics, designers can therefore provide complex technology, improve interaction between the user and product, as well as enhance opportunities for self-expression within the context of the product environment [9]. Yet even with advanced ideologies in the relation to the consumer, prosumer and the artefact, no consideration has been taken which seriously addresses post-processing of ELFDM produced artefacts. This persistently remains in the blog makerspaces, rather than developing as a serious academic field of its own.

In the AM industry, 3D printing failures are seen as a mistake, but fine arts embrace this as part of the creative process and natural evolution of an artefact. On Flickr there exists a website to document 3D print failures as artworks [10]. However, as 3D printing availability grows it is slowly starting to capture more attention from researchers who recognize the profound shifts that the technology can have in science, manufacturing and the arts.

Mary Hale Visser, Professor of Art from Southwestern University, curated an exhibition in 2015 addressing the impact of 3D technology and how it influences the human mind to blur the boundaries between art and science [11]. She says that, "…most of the publicity surrounding the invention of 3D printing has been focused on the rather mundane objects like small replicas of toys that anyone can now make with the aid of a personal 3D printer. What has not been discussed is how this technology will change the way in which human beings think creatively and its impact on various fields of knowledge. 3D printing knowledge is different from other forms of knowledge in that its impact has occurred across many disciplines."

The artists and speakers she chose for the exhibition were researchers of 3D printing technology in the Fine Arts and Sciences. There clearly seems to be more leniencies from fine arts to cross-pollinate the two fields.

- **Art ideologies that currently implement 3D printing in practice as artefact or process:**

Artists like Sophie Kahn shed some light on the implementation of 3D printing in her art. Apart from the fact that she uses 3D printing as an intermediary process phase, she does not recognize a 3D printed artefact as a finished artwork in itself [12]. Instead of focusing on 3D printing as additive manufactured end product she uses it as a tool/ or process to produce her artworks (Fig. 2 below). Furthermore, she uses post-processing techniques like abrasive sanding in her art works, recognizing the limitations to the technology as well as the need for a further process in the finishing, even on the High-end fused deposition modelling (HEFDM) spectrum.

Figure 2. 3D printed sculpture heads. Cropped section. (image courtesy of the artist from http://www.sophiekahn.net/)

Kahn says that ELFDM fabrication allows her to experiment and test quickly without exorbitant costs, whereas her work was previously limited due to expenses. Another very crucial point is that for some artists and designers the production process plays a very important role in the presentation of the final artefact.

The pre-production design phase is physical, followed by the 3D printing production phase which is automated, and lastly the post-processing phase (PPFTs), that becomes physical again. For some artists this process becomes just as important as, or more important than, the actual artefact. The process becomes the artwork.

Museum programs like the Out Of Hand exhibition have started to address the divide between art, design and new technology by introducing training programs at the Museum of Arts and Design in New York [13]. It is the ideal platform to address hard skills development programs to introduce post-production finishing techniques as it commonly deals with the nature of craftsmanship and engages with the process of materials, techniques, forms, patterns and concepts.

This exhibition critically examined the trends in contemporary digital design and fabrication. It examined artworks created through technology fabrication as a tool. The artworks included works spanning from 2005 to 2013. One of the themes discussed were: Is the artist or designer's hand ever really gone from the process? What are the different processes of digital fabrication? How are artists combining traditional artisanal techniques with new digital media? This clearly shows a trend to incorporate new technologies into the traditional art medium. However again, no emphasis was placed on PPFTs even though it could function as the ideal platform. The museum manual describes that sequential step processes should be developed and utilized by instructors, however the inclusion of post-processing remains elusive.

When observing the current guidelines of the production phase of digital sculpting it can be seen that due to technological advances over the last two decades, tools for producing digital art have become more refined, common and accessible. The term, digital sculpture, is most often used to describe various digital fabrication processes, including computer-aided design (CAD), computer-assisted manufacturing (CAM), CNC milling and/or Rapid Prototyping processes [14]. Again, these do not include any mention on post-processing nor including it as an addition to AM production of artefacts. When briefly observing the background of digital sculpting, it can be seen that some sculptors used technology both in the preliminary design and the execution of the physical object, while others created works that exclusively occur in the virtual realm, represented in the form of CAD model or animation. Often only three methods are recognized in the design process namely: modelling, sculpting and scanning.

Post-processing is not always readily accepted in HEFDM additive manufacturing processes as a separate developed field, creating a stigma around the quality and validity of entry-level produced artefacts. However this viewpoint hampers the development of post-production finishing techniques.

3 METHODOLOGY

A sequential explanatory mixed method research approach was used to collect quantitative and qualitative data for the research topic, however for this paper mostly results from the applicable qualitative paradigm were reflected upon. As the research did not intend to focus on quantitative data that recorded costing models for artefact production, it was nonsensical to direct focus on such data; however comprehensive qualitative data from specialist respondents was collected because the quality of artefacts are determined by human opinion, not just empirical data. Cost analysis models of different institutions vary tremendously depending on the purpose of the artefact, thus collecting such data is of less importance than to test and analyze the artefacts by interviewing specialists.

This paper is written from an artistic perspective, it should be observed from an aesthetic background, because human interpretation adds value onto objects through Marxist commodity [1] fetishism. Trends and ideologies determine value sentiments from an artistic viewpoint whereas empirical data, tensile strength and surface profiling determine quality from an industrial design perspective. The term Industrial is used here in the sense of a collective term for everything that is not fine art related. Therefore it includes engineering, design and commercial application.

3.1 What methods of data collection were used?

3.1.1 Initially, an experimental pilot study was executed to determine possible techniques that could be used for PPFTs. The findings led the researcher to explore the use of acetone as a post-processing medium.

3.1.2 Next, a quantitative data analysis was explored to determine the scientific effect of acetone on ABS produced artefacts. This was mainly done by tensile testing and surface profile

[1] As seen in Das Kapital. Volume one: Chapter 1, Section 4: pg. 47. The fetishism of Commodities and the Secret thereof. The social aspect of human value interpretation towards objects. In art, 3D printed objects, even when failed from a technical point, can be interpreted as successful or valuable when observed from a qualitative aesthetic perspective.

measurements collected at various institutions in South Africa and the United Kingdom.

3.1.3 The findings of the quantitative data were then used as a base template to create qualitative questions for the next phase. As we saw earlier in the literature it is evident that human interpretation and human value determination plays an important part in artefact aesthetics. From these questions, two sets of data were collected in the form of interviews and online surveys. Artefacts were reproduced for these qualitative interviews.

3.1.4 Lastly, these data sets were compared with each other and interpreted to surmise if a need can be identified to develop PPFTs for ELFDM and whether it will lead to a niche market.

Owing to its ready availability, an UP MINI 3D printer with a build size limitation of 120mm cubed was used to produce all the components of the artefacts. All the artefacts were larger than the printing bed platform, obligating the need to slice the CAD files into sections that were reproduced separately. This was necessary to illustrate the need to fuse the artefacts in post-production whereby the researcher could test the post-production assembly technique using ABS cement glue.

The artefacts chosen had all been previously produced on high-end (SLS) methods, making them ideal to compare with ELFDM. Thereafter, all the components of the artefacts were assembled and a post-production finishing technique in the form of acetone vapor finishing was applied. It needs to be noted that all artefacts were reproduced in duplicate and none of them was completely finished off so as to illustrate the limitations and/or successes.

The whole production process, with failed prints, weight, separate components, assemblies, production lead times, PPFTs and finishing lead times were documented, so comparisons could be drawn. For quality control, the same printer settings for optimum results were chosen and quality of print was chosen over shortening of lead times. The printer was set to 0.20mm layer thickness, with a solid infill, fine quality and activated thin wall function. The part orientation was set to 45 degrees with 6 layers density and the support generation was set to 30 degrees orientation with a 3 line density. Lastly, the stable support function was activated.

A short visual summary should be reflected on to demonstrate the artefacts and what they were originally intended for, thereby creating context for the artefact aesthetical value purpose. Each artefact and respondent were carefully selected for their contribution to the AM industry from various sectors.

Respondent one and two designed their artefact originally as a functional fashion and art object. It was an international collaboration between South Africa and the United Kingdom. Respondent one is a Digital sculptor from South Africa and respondent two a Digital artist and designer from the UK. Fig 3, below illustrates the unassembled components of the ABS produced artefact, the SLS and ELFDM versions of the artefact.

Respondent three created his artefact from a fine art perspective as a fine art piece and the assembly techniques are very clearly seen on the surface [Fig. 4].

Respondent four created this international competition entry artefact originally on SLS and noticeably the smaller size can be observed in Fig. 5, the ELFDM had to be reproduced much larger to accommodate limitations in the micron size extruded by the desktop printer.

Figure 3. "*Divine Intervention*". Top: Unassembled. Middle: Assembled ELFDM artefact. Bottom: SLS Plated artefact. Image courtesy of the artists available at: http://bunnycorp.co.za/digital-sculpting-and-manufacturing/

Figure 4. Untitled. Image courtesy of the artist. Top: Assembled artefact. Bottom: Acetone and paint treated artefact.

Figure 5. Time. Illustrating the SLS print to the left and the ELFDM print to the right. Image courtesy of the researcher.

Respondent five produced his artefacts on SLS and ELFDM in the past and this artefact was intended as a commercial trophy for a corporate client. Below is a video still from the interview as well as an insert of the artefacts [Fig. 6].

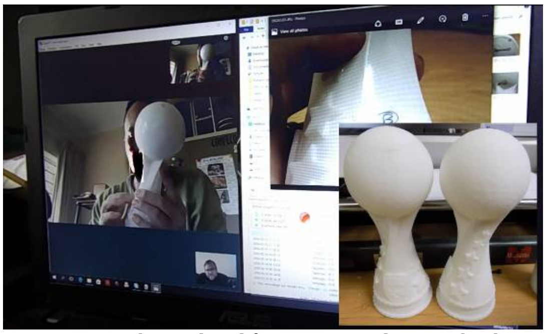


Figure 6. Trophy produced for ELFDM and SLS technology

Lastly respondents six artefact was produced for the high-end fine art and design industry. It was originally created in SLS and then reproduced on ELFDM technology for this study. Fig. 7 below demonstrates both technologies, with the ELFDM artefacts to the left.

Figure 7. *"The Rocking Springbuck"*. Top: ABS ELFDM reproduced artefacts. Bottom: Original SLS artefact. Image courtesy of the artist available from: http://nomili.co.za/?page_id=157

As can be seen from the above figures a limited number of respondents were chosen for their specific skill set and background in AM and/ or fine art. In total 6 respondents participated as it was deemed more important to collect expert responses rather than randomization of the focus group.

Below are the findings of the tests and experiments that documented the complete production and post-production phases, with particular attention being paid to the time constraints, build size restrictions and quality of the artefacts. In short the quantitative results will be mentioned under this section but focus is directed towards the results of the qualitative phases. The reader should therefore note that although thorough quantitative data was collected by means of tensile testing; these results was mainly used to formulate the questions for the qualitative phase of the research.

4. RESULTS

4.1. Pre-experimental pilot study.

An experimental pilot study was originally conducted to determine different PPFTs. An assortment of engineering and artistic techniques where used to expose ABS artefacts.

Acetone was determined as the most likely candidate to expose ABS plastic to assemble different components as well as manipulate the surface texture. Both of which could lead to improved aesthetic value outputs for ELFDM produced artefacts. Fig. 8 below clearly shows in blue where the artefact was cemented together as well as the glossy finish of acetone.

Figure 8. Top: Blue colored acetone cement applied to components that needs to be assembled. Bottom: Completed assembled area after acetone vapor treatment. Images courtesy of the researcher.

No quantitative results were collected during this phase, which necessitated the next phase where tensile test where collected and analysed.

4.2. Quantitative testing and analysis.

Initially the researcher only had access to a Monsanto W-type tensometer and did adaptive dog-bone test specimen analysis (fig. 9 below). Both acetone vapour and acetone dipping (bathing) were tested.

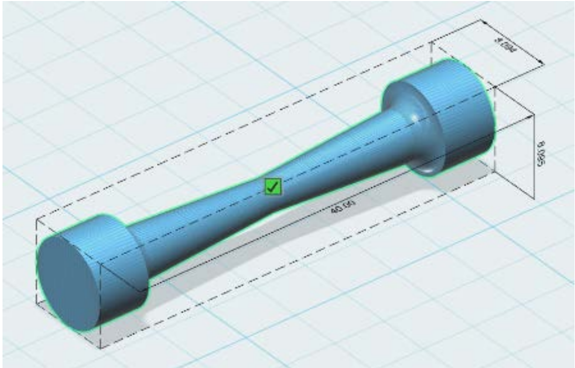


Figure 9. Dimensions of dog-bone pull test strip for w-type tensometer tensile test.

The results clearly indicated that acetone has a negative effect in the tensile strength of the ABS specimens as can be seen fig. 10 below, where a very clear decline in strength can be observed.

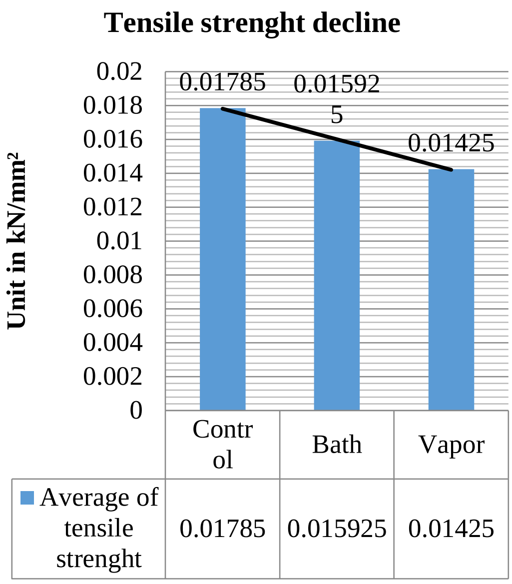
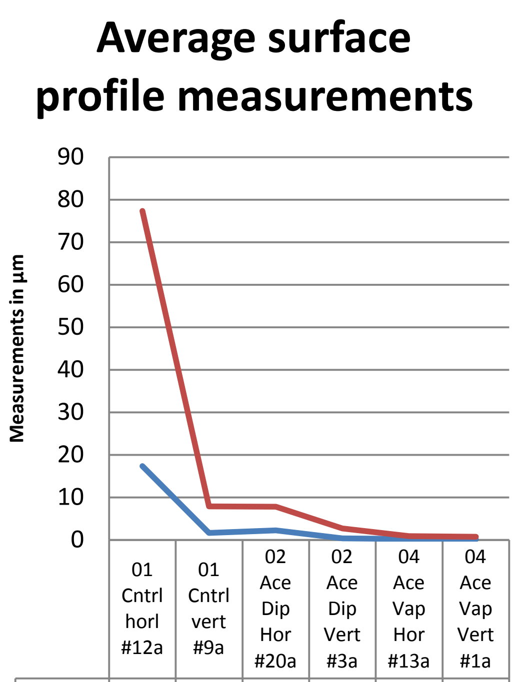


Figure 10. The effect of acetone on ABS FDM dog-bone test

However to corroborate the results of the first test specimens the whole tensile test set was repeated on an INSTRON tensometer by implementing the ISO 527-2:2012 SABS standard test dog-bone specimen specification. These test yielded similar results, showing a decline in tensile strength.

Similar to the above mentioned tests, surface profile measurements were recorded by means of a MITUTOYO Surface tester SJ210 machine. The results indicated that acetone caused a decline in surface roughness, suggesting that the artefacts is visibly more aesthetically acceptable (fig. 11). The following abbreviations should be noted for fig. 11: Control (CNTRL), Acetone (ACE), Dip (DIPPED), Vapour (VAP), Horizontal (HOR), Vertical (VER) and number of specimen (#).



	01 Cntrl horl #12a	01 Cntrl vert #9a	02 Ace Dip Hor #20a	02 Ace Dip Vert #3a	04 Ace Vap Hor #13a	04 Ace Vap Vert #1a
Ra	17.395	1.659	2.267	0.405	0.221	0.154
Rz	77.376	7.8875	7.828	2.72	0.883	0.719

Figure 11. Average surface profile indicator for acetone infiltration on ABS FDM printed samples

These tensile tests and surface profile measurements therefore assisted in asking critical questions to examine when interviewing the respondents. Further in depth analysis of the above quantitative data would steer the research in the opposite direction of what this paper intend to investigate.

4.3. Time constraints

Fig. 12 indicates the lead times for the production and the post-production phases of each artefact set. This was done to establish whether the PPFTs took longer than the production lead times. The original artefacts were produced on SLS, therefore creating a one-part-print. On the ELFDM all the components cannot be produced simultaneous on the same printer, hence the part production and post-production phases were recorded and compared to one another.

It demonstrates that more that 66% (4 out of 6 artefacts) of the PPFTs' lead times were less than the actual production time.

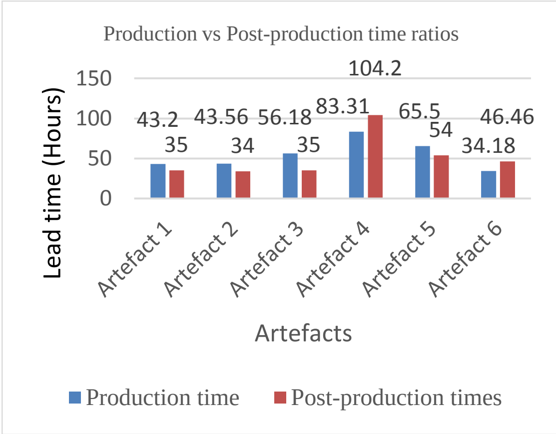


Figure 12. Production vs post-production time ratios

4.4 Build size restrictions

The original (high-end manufactured) one part artefact was compared to the number of parts it would take to recreate on entry-level technology. Artefact one was produced at a ratio of 4 to 1, artefact two at 4 to 1, artefact three also 4 to 1, artefact four at 65 to 1, artefact five 3 to 1 and lastly artefact six was produced at 13 to 1 ratio [Fig.13].

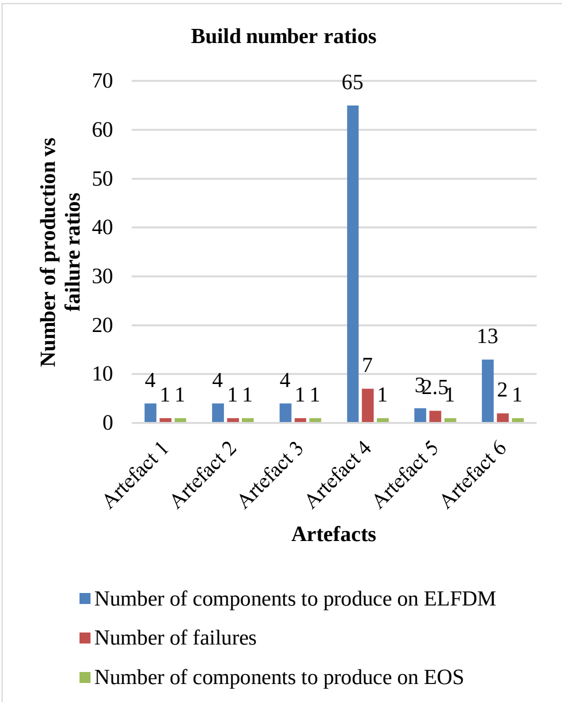


Figure 13. Number of production vs print failure ratios

4.5 Layer quality and aesthetic appearance

For this section, the respondents who were interviewed had to give a detailed explanation of their expert opinions. The topics discussed were their overall opinion of the reproduction of their artefacts; which areas were most successful when PPFTs were applied, whether ELFDM with PPFTs could compete with HEFDM/AM and the skill set influence of the finisher, and, lastly, what improvements could be made and their view on the future of PPFTs for ELFDM in general. Below is a summary of the findings:

4.5.1 The respondents were asked about their overall viewpoints on the reproduction of their artefacts as well as the PPFTs that were applied and they responded with the following results:

The first respondent was impressed with the quality and saw improvement on the surface profile after PPFTs were applied, making the artefact aesthetically pleasing. He did not agree that artefact-failures can be seen as aesthetically acceptable. The second respondent was impressed by the detail as the original file was designed for SLS and said that the PPFTs made the visible step layers less. He felt that the assembly techniques worked well and that acetone eliminated the surface texture mistakes. He felt the aesthetic appeal is less disturbing when applying PPFTs.

The third respondent found the artefact interesting and identified where the acetone increased the quality of the surface, however he only found the assembly techniques partially successful. The same cracks made the artefact more aesthetically pleasing. The fourth respondent was pleased with the artefact but disappointed that the reproduction had to be scaled up, due to quality loss, she felt the post-processing finished off the surface successfully, but pointed out that if a less polished surface is required acetone might not be appropriate. This respondent also found the visual aesthetic appealing and that without PPFTs the artefacts would not have been successful on ELFDM technology.

The fifth respondent was satisfied that acetone controlled the suppression of step-layers but with loss of detail. He indicated that with continued exposure to PPFTs, the artefacts might become commercially acceptable and concluded that the artefact is successful as a once off aesthetically pleasing object but would become problematic if it is to be reproduced in batch production.

Respondent six was impressed by the fact that ELFDM could produce complex geometry. She hypothesized that if you know the limitations you can eradicate most of the problems and that these techniques might assist in narrowing the gap between entry-level and high-end AM processes. Previously she would have preferred to incorporate step layering into her design; now these PPFTs make it easier to do post-processing. For the high-end design market that needs to be perfect, the aesthetic appeal was unsuccessful, however if seen from an engineering perspective as a visual aid or prototype it might be aesthetically pleasing. From an artistic perspective it definitely is aesthetically pleasing as a finished artefact as well as an armature.

4.5.2 The respondents debated which areas they found to be most successful and whether the post-production finishing techniques improved or made the quality of the artefact worse:

The first respondent felt that the areas completely smoothed by the acetone were most successful and that it improved the quality of the artefact. The second respondent felt the PPFTs improved the quality of the artefact although it is not showroom ready as the artefact was not completely surface-finished. For respondent three the areas that had accidental acetone infiltration (flaws) were most successful, as the application of the acetone ABS cement made the surface look like skin pores. He found that the PPFTs did improve the quality of the artefact. The next respondent felt the areas that were completely assembled and finished smoothly to be most successful. For her the PPFTs definitely improved the quality of the artefact.

Respondent five preferred the uniformity of a smooth finishing from a commercially viable viewpoint. He felt that the PPFTs definitely improved the overall quality of the artefact. For respondent six the areas where most of the step-layers have been removed were found to be the most successful. It was felt that PPFTs improved the quality of the artefact and could even be seen as viable comparative to high-end production for certain markets if the finishing is followed through.

4.5.3 Upon asking the respondents whether they feel these PPFTs could compete with the high-end additive manufacturing processes and the involvement of the finishers' skill level they had the following to say:

The first respondent did not feel that the PPFTs made the artefact ready to compete with high-end manufacturing due to multiple production levels of ELFDM, timeous lead times and that the ABS material is weaker than high-end materials. He does however recognise that high-end production designers make use of entry-level technology, for example shoes, but skill level plays an integral role. The second respondent argued the success of PPFTs on the grounds of lowered costing. He also felt the skill of the finisher is important. The third respondent felt that PPFTs could compete with high-end manufacturing if artists and designers experiment more. He surmised that the skill set is linked to the specific industries but is important.

The fourth respondent felt that PPFTs would afford the artist larger models more cheaply if you bear in mind that the artefact is design specific. For her the skills of the finisher are also important. The fifth respondent felt the quality of the 3D printers cannot compare yet but the development of hard skill sets could bring PPFTs for ELFDM closer to compete with high-end industries. The sixth respondent concurs that if the artist takes design specific conception into consideration then PPFTs could viably assist ELFDM to compete with high-end manufacturing. She too agreed that the skill set of the finisher should play an important role.

4.5.4 Lastly, the respondents were asked to suggest improvements for the step-layering,assembly techniques, surface finish and aesthetic value output of the artefacts. This was followed by their opinions on the future of these techniques in additive manufacturing as well as their recommendations and suggestions.

The first respondent felt step-layers can be improved by focusing on better planning in pre-production, surface-finishing by more skilled abrasive sanding, as well as developing ratios for acetone cement to improve the assembly techniques and lastly developing specific tools for PPFTs. He specifically states that although he has always advocated PPFTs in South Africa, the techniques are lacking and that they will be crucial in future additive manufacturing. In his words: "…the finishing is actually the key of taking 3D printing from just doing prototypes to selling products in the market**".**

The second respondent felt improvements could be made through hardware development. He suggested skill development and design-adaptation could improve PPFTs. He concluded that PPFTs' adjustments could assist entry-level ABS to be recognized as a higher valued production material to compete in high-end additive manufacturing industries. The third respondent felt that enhanced abrasive sanding and acetone exposure would improve the PPFTs and that it would assist end user production.

The third respondent suggested that improved control of PPFTs through skills would result in less detail loss. Of noticeable interest was that she did not agree that PPFTs would influence the current state between entry-level and high end production. She saw PPFTs developing as their own separate field. Respondent five felt that part orientation could enable step-layering to be prominent, but that there are many options apart from acetone to use as PPFTs. He stated that PPFTs could viably develop in parallel to high-end manufacturing depending on the need or use of the artefact. He suggested the formalization of hard skills development and foresees that it will lessen the gap between the high-end and the entry-level industries.

Respondent six suggested that an overall thorough approach to finishing could eliminate surface roughness. She concluded that for the artist and small business end-user the use of PPFTs would become more important, but not in the mass production arena.

4.3.5 Online survey:

An online survey was conducted as a corroborative measure to the open-ended interviews. These surveys included a majority of closed-ended questions to conclude and summarize the respondent's viewpoints on the successes and failures of using PPFTs for ELFDM. The online survey was conducted anonymously so the researcher would stay impartial to the finding data, especially after the previous interviews. Below are the findings of the online survey.

50% of the respondents determined that PPFTs are very important for ELFDM, 33% as important and 17% as moderate, indicating all responses felt it was important.

50% of the respondents determined that PPFTs are moderately successful for ELFDM, 33% rated it as successful and 17% as very successful. This indicated that all respondents rated PPFTs as successful for ELFDM.

83% of the respondents agreed that PPFTs could establish a niche market to compete with high-end manufacturing, 17% decided it would only be successful as display models. It therefore indicates that all respondents agree that PPFTs could narrow the gap between entry-level and high-end production.

83% of the respondent felt that the ABS acetone cement was successful as an adhesive method on ABS artefacts, but the other 17% were indecisive.

67% of the respondents felt that splitting the artefacts into components was successful to accommodate the size restriction of the build plate size.

50% of the respondents did not feel that the structural integrity is compromised by acetone cementing, however 33% did think it weakens the structure of the polymer.

100% of the respondents felt that PPFTs improved the aesthetic value of the reproduced ELFDM artefacts. The artefacts are therefore visually more appealing after surface finishing was done with acetone.

83% of the respondents agreed that there is a good chance of acetone finishing competing with high-end additive manufacturing.

5 CONCLUSION AND THE FUTURE OF ELFDM IN ART AND RECOMMENDATIONS

The aim of this paper was to establish whether the use of acetone could successfully enhance the use of PPFTs for ELFDM and, by doing so, establish a niche market where more users can utilize the additive manufacturing technology.

Throughout the paper, various literature pointed to evidence that PPFTs are utilized in the online makerspaces, public spaces like universities and museums, were discussed. However no formal documentation system or academic hard-skills training modules have been developed. This indicates that not enough focus is placed on the entry-level industry at present. Not only will such skills development programs develop ELFDM but assist in establishing a post-processing market.

However to see if such a niche market could provide cheaper alternatives and whether it would narrow the gap between entry-level and high-end production, it was necessary to first test the influence of acetone on ABS ELFDM artefacts to formulate a comprehensive viewpoint. This in turn assisted the researcher to interview experts to obtain a thorough perspective on what is seen as aesthetically acceptable standard according to industry.

Although the results of the tensile testing clearly indicate that the use of acetone does influence the structural integrity and mechanical properties of ABS produced artefacts, this was not the focus outcome of this paper. The paper did not intend to determine or examine the tensile properties of the acetone exposure, but rather to utilize it to assist the researcher in formulating qualitative questions about the respondents' expert opinions on aesthetic value of artefacts exposed to acetone. Instead the research focused on AM value chain processes and the resulting qualitative opinions of the respondents.

When observing the restrictions, it could clearly be seen that post-production lead times did not hinder the overall lead times. Only a small number of PPFTs took longer than the production time. For the build size restrictions it was also evident that whilst most artefacts only had to be split into a couple of components, there was one that had a 1 to 65 part ratio. Furthermore most respondents agreed that the assembly of such components did not cause degradation in the aesthetic appeal of the artefacts.

All the respondents felt the artefacts impressed them where the acetone improved the surface quality and felt PPFTs made the artefacts aesthetically pleasing. With the artist-respondents it was concluded that even the outcomes that deviated from the original input design could be incorporated into the final artefact. The only setbacks noted were that excessive acetone exposure could lead to part geometry deviations and that batch productions could become problematic; however this can be improved with the skills development of the finisher.

The most successful areas of finishing were noted where acetone exposure took effect. All of the respondents agreed that the quality of the ELFDM artefacts is increased by acetone post-processing. All, except one respondent, felt that the PPFTs could compete with high-end production machines. They motivated cost as a major factor as to why ELFDM PPFTs could enter the market. Hard-skills development was repeatedly identified as a motivating factor in readying ELFDM to compete with high-end additive manufacturing.

Planning in pre-production, hardware development and skills development are suggested as the main areas of development that will assist PPFTs for ELFDM.

The survey concludes that PPFTs are seen as successful, that they would assist ELFDM to establish a niche market by addressing the limitations and that entry-level-produced artefacts are aesthetically more acceptable after post-production finishing techniques had been applied. All of this provides evidence that PPFTs will prepare ELFDM to compete with the high-end additive manufacturing market.

It is recommended that a future program for the development of PPFTs as a tool or medium for artists and designers should be investigated. Hard-skills development programs should be designed in a future study and be subjected to field work investigation. Cost comparison models should also be investigated to provide clear evidence for the production and post-production phases.

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