MODEL, PRINT, SHOOT, REPEAT: AN INVESTIGATION INTO THE IMPACT OF 3D PRINTING AS A TOOL IN THE STOP-MOTION ANIMATION INDUSTRIES.

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Abstract

This thesis investigates the use of 3D printing as a digital tool within the stop-motion animation industries, uncovering how this technology has affected and continues to affect the animation processes and those working with them. This is achieved by first placing 3D printing in context alongside stop-motion history and development, signifying it as an important new technology within animation practice for features, commercial, short-form, and auteur productions. Through interviews with leading practitioners in the industry and examination of many of the major studios that have led the way or otherwise adopted the technology to great effect, a thorough analysis has been conducted to categorise, define, explain, and contextualise the use of 3D printing technology within the stop-motion animation process and within various theoretical considerations.

Through practical investigation, an understanding of the technical skill and processes required to use various 3D printing technologies and materials has been achieved. Action research has been used to develop collaborative case studies with industry professionals; these have been designed to explore and demonstrate the main theoretical questions that have arisen from the research regarding craft skill, authorship, and novel aesthetic profiles achievable through this technology. Throughout the thesis, these considerations are explained and discussed to provide a factual, balanced framework for further research. These findings are used to assess current materials and technologies, develop a framework for auteur filmmaking, and explore the aesthetic potential of 3D printing in the near future.

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Chapter 1. Introduction

Stop-motion is an animation method that has enjoyed enduring appeal and popularity despite a seemingly archaic creation process that baffles and eludes some. In a world where every conceivable scenario can be rendered in high-definition CGI, why would an audience be willing to sit and watch a bunch of objects be shuffled around a set by a crew of obsessive Luddites? And why would any technologically savvy craftsperson still want to make work in this labour-intensive way? In his article on the film *Frankenweenie*, Guardian writer David Cox formally discredited the medium of stop-motion, calling it both the “low-rent option” and “a totem for the digital-disdaining classes” (Cox, 2012). His principal point of ridicule is heavily based upon his biased belief that CGI is the superior of the animated modes, in its ability to not only visually but also financially surpass its ‘craft-centred’ ancestral brother. This strangely misguided and most likely ‘clickbait’ style article—aimed at irritating fans of the medium—struck a chord with me back in 2012.

Not only is this article poorly researched—it overlooks much of the complexity of not only the methods of all archetypal forms of animation but of the entire film industry—it also unwittingly does a disservice to both the subject it attacks (stop-motion animation) and the hero of the piece (computer-generated animation). Firstly, Cox claims that stop-motion relies purely on its aesthetic process-driven ‘methodology’, whilst also condemning LAIKA’s use of integrated CGI on their most recent film at the time *ParaNorman* (2012), referring to it as “cheating”. Secondly, by determining the worth of both mediums largely through their production costs and their box office takings, Cox does a disservice to the artistry of both mediums—and also shows a relatively narrow-minded view of cinema as a whole. He does, however, acknowledge certain recurring misunderstandings which I will seek to address through this study, by dismantling the ideas that stop-motion is an altogether digital-distancing craft and that stop-motion as a visual medium is defined by a singular aesthetic. As a technology that is simultaneously digital and physical, 3D printing[1] offers a unique dichotomy, making it an ideal tool to explore the post-digital and hybrid world that stop-motion production operates within.

[1] As a matter of clarity, I will be referring to the process, machines, and technology throughout the thesis as 3D printing, rather than rapid prototyping or additive manufacturing unless directly quoting or in reference to specific rapid prototyping department or job title, that use the other two. As a more general and more widely accepted term, 3D printing describes more readily the process and the physical end product, as not all 3D printing, is used for prototyping (Hoskins, 2018:37) and although more accurate in its description additive manufacturing (2018:38) has technical and industrial connotations that are not always applicable to the process or ways of working presented throughout this study.

Historically there is of course a legacy predating 3D printing. Contemporary culture has gone through the usual rounds of excitement, fear, and acceptance, leaving in its wake questions that must be addressed regarding the longer-term effect it has had on craft skills, labour, authorship, aesthetic profiles and ultimately artistry, concerning the look, inferred meaning, narrative, and the individual desires or needs of the creative. 3D Printing as technology offers new materials, new processes, and new working methods, doing so seemingly at the click of a button. However, this greatly undermines the skill and knowledge required to use the technology effectively and creatively. Significant effort has been made to understand the process and skills required in the use of this technology through the use of practical examples and processes, not only from a theoretical or academic position but also from experiencing the technology first-hand, in order to gain the best understanding of the decisions and ideas that are at the core of stop-motion animation production. This has also been achieved by researching, documenting and talking to creative individuals working in all areas of the industry to uncover how they have incorporated 3D printing into their manufacturing and filmmaking processes and cataloguing how 3D printing has been used in almost all areas of stop-motion production to date.

In order to address questions regarding the effect 3D Printing technology has had on the industry, I have systematically broken-down key theoretical and practical aspects of the process of 3D printing technology as it pertains to the physical medium of stop-motion. First by understanding the craft of stop-motion as a whole, as well as the skills involved with using digital tools as devices that allow for a range of construction possibilities, highlighting 3D printing as an innovative way of working for makers in and outside of mainstream animation production. By tracking the continuous development of the technology including quality, detail, strength, durability and the ever-expanding range of novel materials, an understanding of its use in various areas of fabrication can be established. Through my analysis of the use of digital tools available to model makers, animators and filmmakers, connections are drawn between theory and practice while also investigating its application at a number of scales of the industry that may seek to continue or employ these technologies in future. After overviewing the skills, technologies and materials available through 3D printing, this knowledge is enacted into a practical investigation that seeks to test a range of machines and materials to provide a detailed understanding of the process of manufacturing 3D printed parts, their strengths and their potential use, both through this study and within the industry as a whole.

This is followed by insight into levels of authorship that can be found at different scales within stop-motion industries, with a focus on both larger studios that create commercial and feature productions and the work of ultra-auteur filmmakers, who produce much of their work by themselves. This research offers not only insight into the continued levels of labour and creative control afforded by 3D printing but the value it brings to production and the impact it has on individual creatives working within the industry. These findings are then demonstrated through practice in the development of a case study with an ultra-auteur filmmaker, to identify how this technology may give further authorial control to those working within an auteur framework. Through the development of new knowledge and new ways of thinking, an expanded toolkit of skills and ways of working can develop film-making practice.

The final section looks at the aesthetic potential afforded through 3D printing and how this has continued to be developed through technical innovation in machines and materials as well as design strategies. Multiple theoretical considerations are explored to identify the way in which the aesthetic of 3D printed stop-motion production can give an increased level of nuance to the performance, moving toward animated realism and potentially bordering on the uncanny. There is consideration given to other ways of working, that both pre-date and have been developed alongside 3D printing use for facial animation. Alternative design ideologies using 3D printing also offer alternative methods for creating, demonstrating a post-digital position to 3D Printing, exploring its inherent materiality using imperfections in the prints themselves as part of the visual or narrative construction of the work. These ideas are explored further through the final case study that follows the development of a micro short film that demonstrates the visual, textural and narrative potential of 3D printing. This study contextualises the impact of 3D printing as a technological innovation within the stop-motion animation industries and makes suggestions for future use, by defining a solid framework for the understanding and use of 3D printing for all levels of the industry, as well as suggesting potential future considerations, which in turn represents the main contribution to new knowledge within this study.

1.2 Parameters of the Research

Based on my experience as an animator and filmmaker, I have developed an exploratory, artistic approach to new technology within various methods of animation production that influenced the study I present here. In the development of the aims and objectives for the study, a focus was placed on the physical, visual, and cultural considerations that arise when 3D printing is used during the production of stop-motion animation. To achieve this, empirical methods of investigation were used in the development of practical case studies using action research to give further depth to both my and the readers understanding of the skills required to engage with this technology and this mode of filmmaking. As with any research focused on the development of current or new technologies, as the study progressed more work in the field was continually discovered and addressed. A theoretical framework was developed to address the central themes and areas of discussion that arose throughout the study.

As with any long-form project such as this, certain parameters needed to be put in place in order to define the focus of the study. As such, an in-depth investigation into potential environmental or health and safety concerns of 3D printing as it relates to the relatively small industry of stop-motion was considered too broad for a study of this length. Although initial research and exploratory questions were asked in this vein, without considerable collaboration and support of either an environmental or materials scientist as part of the study, a worthwhile investigation into these areas was considered outside its scope. Similarly, a thorough cost comparison analysis was considered superfluous, due to the highly nuanced and bespoke nature of stop-motion creation, and a sufficiently detailed or repeatable study of this was not considered beneficial to an understanding of the technology as it relates to the creative, cultural, or emotive potential for animation. Although the cost of printed materials as they relate to the wider range of topics discussed throughout the thesis have been included and discussed with practitioners in the field, the ever-evolving nature of the technology means costing remains relative to the individual, studio, or process of printing.

As Paul Ward highlights, “the relationship between practice and theory is especially acute in the field of animation studies” due to “the notion of craft and artistry that are attached to animation as an activity, and the fact that animation is so diverse” (Ward, 2019:8). He goes on to cite the impact of technology on animation, and the changes it has elicited as “one of the key areas in need of analysis” (2019:101). Though much research has been conducted to explore these areas, a significant analysis of 3D printing impact on the animation industry has not yet been completed, and this study contributes greatly to knowledge in that area. Every effort has been made to seek out the most innovative uses of 3D printing within animation production, with many of the first or most relevant/innovative examples being referenced and discussed—particularly in the second, third and seventh chapters of this thesis. Many others have not been included due to duplication of concept or the relatively small word count permitted in this thesis. There is also of course the possibility that I may have missed some interesting projects, for which I can only apologise and hope the omission does not lessen in value the content that follows. Although much work has been done to contextualize 3D printing use within the wider history of animation, the ideas and accounts presented within the thesis give the best interpretation of the various considerations its use has taken to date of publication.

1.3 Aims and Objectives

Aims	• To investigate the impact of 3D printing on the visual identity of stop-motion. • To use 3D printing to create novel puppet manufacturing processes.
Objectives	• Survey current practitioners using 3D printing within stop-motion animation. • Plot the historical development that led to the use of 3D printing in stop-motion. • Use interviews and case studies to identify strengths and weaknesses of the use of 3D printing, both visually and mechanically. • Discuss with practitioners the issues surrounding craft skill, authorship, and aesthetic potential when using 3D printing and other digital fabrication tools. • Develop these themes and experiments into practical work/artefacts.

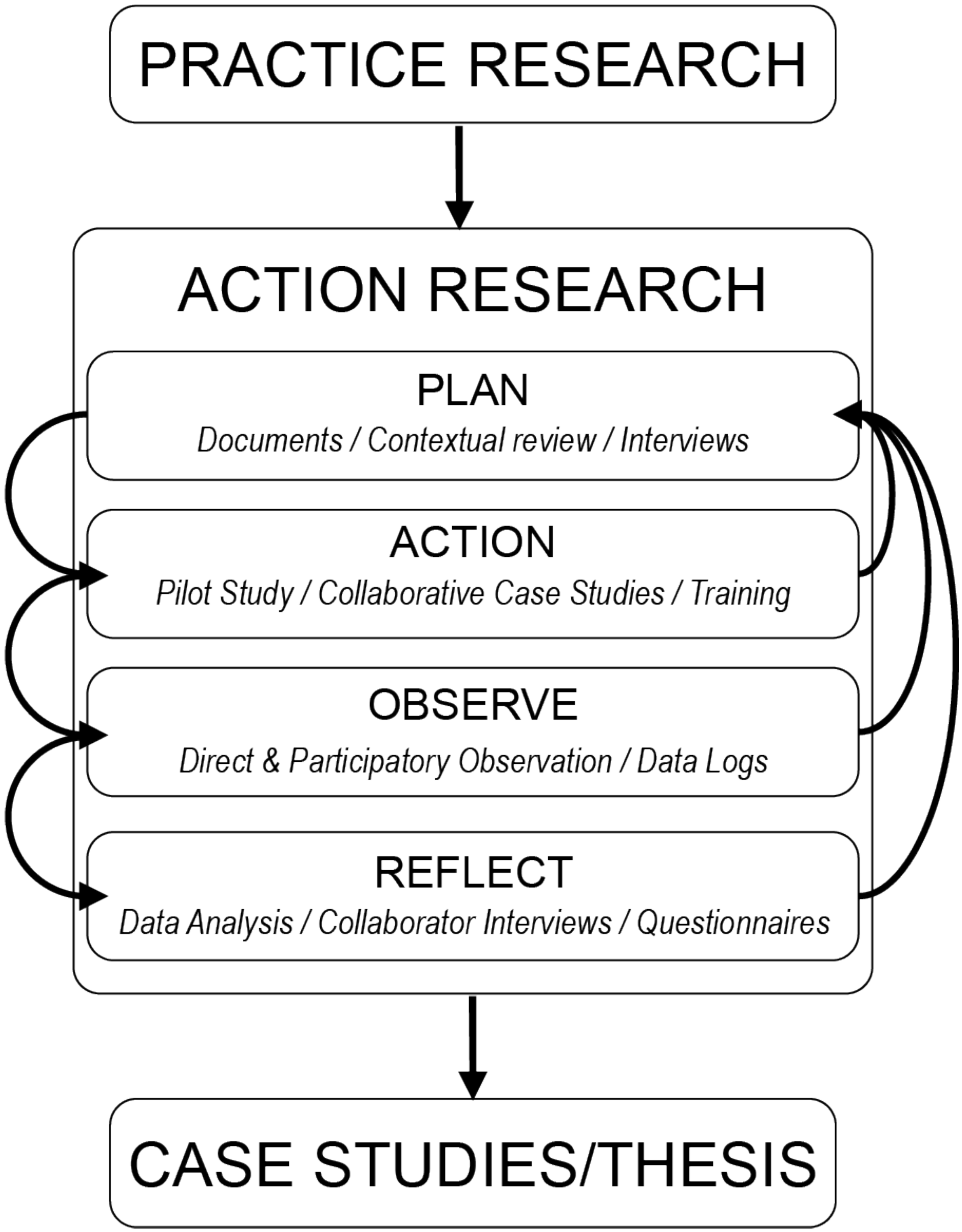
[*Table 1*. Aims and Objectives of Study]

1.4 Research Design: Action Research with Case Studies

In order to achieve my stated aims and objective, an emphasis was placed on a practice-led research investigation as described by researcher Linda Candy as a process that "is concerned with the nature of practice and leads to new knowledge that has significance for the practice" (Candy, 2006:3). Christopher Frayling (1993) identifies three forms of research that may benefit the Arts researcher: "Research into art and design" as research into the historic and/or "theoretical perspective on art and design"; "Research through art and design" as research that involves looking at "materials" or "development work"; and "Research for art and design" as research that produces artefact(s), in which the "thinking […] is embodied in the artefact" and not "primarily" based in written or verbal communication but through the piece itself. Although elements of each form are present in the study, I align much of my research with the research through art and design paradigm, particularly in the way Frayling places emphasis on communicating results through “step-by-step” documentation of practical experiments, contextualised in a final report through Action Research (1993:5); something that Candy also recognises as a defining feature of practice-led research. As Professor Bruce Archer explains:

> There are circumstances where the best or only way to shed light on a proposition, a principle, a material, a process, or a function is to attempt to construct something or to enact something calculated to explore, embody or test it. […] Such explorations are called Action Research. (Archer, 1995:11)

In Action Research (Frayling, 1993; Archer, 1995; Candy, 2006; McNiff, 2016) the focus is placed on “[improving] learning in order to inform new thinking and new practices” (McNiff, 2016:125). As McNiff (2016) explains, the researcher is positioned inside the research itself (16), and the emphasis is placed on the process of working things out (47); this is done using multiple methods of data collection with attention put on “keeping detailed records as a way of gathering data” (51). Action research findings are presented in contextual written form such as reports or theses, along with “empirical evidence […] to establish the validity of knowledge claims” (227). Practice is conducted based on iterative cycles or spiral of practice that follows a procedure of PLAN > ACT > OBSERVE > REFLECT > REPEAT. McNiff advocates for the development of a personal adapted system (116); my own version can be seen in Figure 1 below. This iterative cycle of action research made use of multiple data collection methods.



[*Figure 1*. Action Research Cycle Diagram Used in Study]

I have used action research (Muratovski, 2016) in the creation and testing of practical case studies to explore various theoretical considerations that arose in the contextual review of 3D printed work in the animation industry. This was supported by reviewing numerous secondary documents, multiple interviews, and case studies exploring the practical and theoretical framework discussed throughout the body of this thesis. A similar system of practice research is also suggested by Dr Mark Evans when discussing the role of practice by researchers in which he describes many of the data collection methods I have outlined in the diagram, as well as how “creative practice” can support data collection and signify the major difference between research practice and commercial practice (Evans, 2010).

Case studies proved pivotal in data collection and development of practical research outputs. Robert K. Yin describes Case Studies as “studies of events within real-life context” (Yin, 2003:72) and in this way multiple methods were used to collect data from various sources and perspectives. An extended pilot study was developed (chapter 4), not only to gain the requisite skills to engage with the research subject—namely, working with 3D printers in the development of mechanical and multi-material parts—but also to “refine” the “data collection plans” regarding the content of the data, the procedures to gather it, as well as an opportunity “to develop lines of enquiry” (Yin, 2003:79). As Yin suggested, the pilot study represented one of the most “complicated” phases of the research, taking up more time and “resources” than the other two case studies, but provided a wealth of empirical knowledge of materials and procedures that guided the following case studies developed in collaboration with practitioners (79-80). Through this and the rest of the study, a variety of methods were employed to gather data for analysis and evidence of findings, which as Yin states is “a major strength of case study data collection is the opportunity to use many different sources of evidence” (97). Case studies were used throughout to engage with practitioners and develop artefacts to physically explore the major theoretical considerations discovered during the study.

Documents in the form of books, press news, and industry journals are used throughout this study to gather data for intertextual analysis as well as to develop guidelines of investigation both practical and based on theory (Yin, 2003:87). These documents can be seen extensively in chapters 2, 3, 5, and 7, which seek to contextualise and guide the reader through lines of enquiry that, along with the other methods mentioned, guided the study’s findings.

Interviews provided one of the main methods of data collection, through which lines of enquiry as explained by Yin (2003) were explored through "open-ended" questions (89-90). As with many case study investigations, the impetus of this study was focused on "human affairs" as they pertain to the impact of 3D printing on the art of stop-motion and those working within it. Interviews were conducted with various practitioners who could offer unique "insight into the situation" within the industry (92). Interviews were also used extensively to document discussion with collaborators during case studies, to identify current process as well as offer opportunities for reflective critique. The interview method was selected due to its ability to offer "richer data" and "enhanced insight" (McNiff, 2016:185). All interviews were recorded and transcribed, for analysis; pertinent segments were selected to contextualise theoretical debate or used as data in documenting and reflecting the actions taken through case studies. Full permission was given, and appropriate documents and evidence was supplied in accordance with my ethics procedure discussed in section 1.5.

Direct observations were another key method of data collection throughout the pilot and case studies. As highlighted by Yin, in observing new technologies, direct observations are "invaluable aids for understanding the actual uses of the technology or potential problems being encountered" (2003:93). Similarly, participatory observation, with myself as research participant in the study, was perhaps the most useful and insightful way to collect data as well as gain valuable knowledge from inside the study itself (2003:94). This tacit build-up of knowledge based on practical engagement with the technology is what has provided my study with a higher level of accuracy and understanding than simply engaging from a purely theoretical or outside perspective. In reference to the typology of practitioners as discussed by Mike Wayne (2001), Paul Ward (2019) describes the "different extents to which one can be self-conscious about one's own work" (Ward, 2019:96). Wayne describes "The Reflexive Practitioner" as someone who can "reflect on and interrogate the production process […] and can chart the development of ideas"; "The Theoretical Practitioner […] who directs our attention to the product, the symbolic artefact that has been worked up out of the production process" using "pre-existing (cultural) materials" to "identify the relationship between the choices made in terms of what the text looks like, and the production of meaning in the text"; finally the "Critical Practitioner" that both Wayne and Ward advocate as the more desirable position to occupy as someone "willing and able to think through the implications of what they do and place it in its social, historical and political context” (Ward, 2019:96). These observations were documented through detailed data logs[2] to record “ideas and observations about action” by keeping records of action as they happened, both for recall and data (McNiff, 2016:170). Within these data logs, multiple formats were used to capture data including text, reflective writing, video, and images/photos produced by me and the collaborating practitioner.

Open-ended questions were used in a questionnaire developed for the final review stage for the final case study (chapter 8) in order to garner standard replies from multiple participants for a more widespread thorough analysis (McNiff, 2016:172). The use of questionnaires was partially due to the COVID-19 pandemic, which prohibited or overtly complicated the original plan to conduct focus groups and workshops to reflect on case study outcomes with practitioners. Finally, the creation of physical artefacts as described by Yin (2003:96) offered a synthesis of learning, skill, and reflexivity. Taking the form of puppets (chapter 8) and mechanical parts (chapters 3 and 6), either as physical objects or presented as final films or a making-of video, these articulated in part the stated research aims and objective at the centre of this study, as well as providing further materials for analysis both within this study and for others moving forward. The creation of video materials during the documentation and reflective stages of observation were also brought together into the making-of video as described by McNiff; “mini-documentaries about your practice” aided in explaining and disseminating the research both during the research and after it was complete (McNiff, 2016:154).

Triangulation (Denzin,1978; Patton,1980; Stake,1995; Yin, 2003; McNiff, 2016) is a way of validating research findings by using multiple sources of information or data collection. In reference to Denzin 1978, Patton describes four types of triangulation:

> (1) data triangulation—the use of a variety of data sources in a study; (2) investigator triangulation—the use of several different researchers or evaluators; (3) theory triangulation—the use of multiple perspectives to interpret a single set of data; and (4) methodological triangulation—the use of multiple methods to study a single problem or program. (Patton, 1980:108–9)

In reference to data triangulation as described by Patton, Yin denotes that triangulation encourages the collection of “information from multiple sources but aimed at corroborating the

[2] Data logs can be found in Appendices A.1, B.1 and C.1, the design/layout of which were developed and altered—with permission and thanks—from those of fellow PhD researcher Sophie Zajicek.

same fact or phenomenon" (Yin, 2003:99). Triangulation creates "a reliable and valid set of data" that enables researchers to "move beyond theory-specific investigations to generalized-theoretical studies" (Denzin, 1978:300). As Denzin goes on to highlight, "Multiple triangulations […] [is] the most refined goal any investigation can achieve. With it, all the advantages that derive from triangulating single forms are combined into a research perspective that surpasses any single-method approach" (Denzin, 1978:304). Through this study, I have triangulated multiple sources of data, methods, and theoretical perspectives to produce the most comprehensive evaluation of the current use and impact of 3D printing both on the industry and those working within it, contributing new knowledge regarding ways of working and thinking for those looking to use 3D printing or other digital tools, in regard to skill, craft, authorship and aesthetic style profiles, as demonstrated through the following chapters.

1.5 Ethics

Due to the sensitive and secretive nature of the film industry, questions asked of interviewees had to be kept broad to allow for the participants to manoeuvre around various NDAs and production legality issues. All interview participants, case study collaborators and questionnaire subjects gave written permission for their information to be used throughout the study. All images have been granted permission for inclusion in the final published thesis.[3]

1.6 COVID-19

It is safe to say that almost everyone's way of life was profoundly affected by this global crisis. In March 2020, shortly after my second-year progression review, the first nationwide lockdown was announced, and the university enforced full closure of all campuses. At this stage, I was finalising my long-form pilot study (chapter 4) and was about to start the first and second case studies (chapters 6 and 8). While I, my supervisory team, and the research department began to adjust working patterns, all practical research was halted until access to equipment and facility could be made. At this stage, significant changes needed to be made to my research plan in order to complete the study. As lockdown restrictions began to ease, I was able to negotiate roaming access to equipment to conduct the first collaborative case study (discussed in chapter

[3] A copy of the participant information sheet, permission form, image request form and list of interviews conducted during the study can be found in Appendix D.

6). Strict COVID cleaning and contact procedures added further complexity and additional time that had not/could not have been considered in the original planning of the study. In June, I was successively awarded a funding extension by the UKRI, which granted me an additional six months of funding to address the loss of time due to COVID. After the second case study concluded I was also granted further time and funding, through the 3D3 Individual Studentship Award for a two-month project outside the remit of my own study to work on research supported and funded by Arts Council England and BBC Arts.

Returning to conduct the final case study in September 2020, I was able to adjust my plans ahead of the second UK national lockdown in October. Due to the multiple setbacks to the practical components of my research, I applied and in December 2020 was granted additional funding to purchase a low-cost FDM printer to allow me to conduct the testing needed for my final case study from home. By March 2021 there was increasing access to university facilities, which allowed me to set up a production schedule for the final stages of the final case study; the physical element concluded in May 2021. The global pandemic has significantly impacted my research, affecting the design, timeline, assessment dates, scope, and methods of conducting practical research and review. The most significant change was that it became unfeasible to invite multiple reviewers to campus to discuss and review my practice or to take part in workshops and hands-on research. However, by becoming more adaptable and establishing new ways of working I was able to reach new people, no longer constricted by geographical or physical location. I also became more adept at working, communicating, and disseminating my work through online platforms, which has benefited this study by allowing me to participate in more online talks, conferences, film festivals, and critical debates.

1.7 Previous Research

Formal and academic writings on the subject of 3D printing within the animated form are few and generally lacking in depth. In this way, this study's predominant aim is to address some of the initial considerations and ideas raised by others. Much of the literature and discussion around the subject has taken place in the public-facing journalistic press and will be referred to throughout the body of the thesis. However, regarding published books, peer-reviewed journals, and papers with a dedicated focus on the crossover between 3D printing and stop-motion, Table 2 discusses the most identifiable. Some sources aided in the development of my own lines of enquiry as defined in my aims and objectives; others have been published during or towards the end of my study.[4]

***The Advanced Art of Stop-motion Animation* by Ken A. Priebe (2010)**
One of the first books to note the potential influence of 3D printing within the field of stop-motion animation production, although understandably dated in outlook and consideration for the potential of the technology, it offers a sound base for understanding the process and the development of the technology as well as from where the initial concept was derived, which is discussed further in chapter 2.
***3D Printing for Artists, Designers and Makers* by Stephen Hoskins (2013 & 2018)**
As the founder of the CFPR research group in which my own research was conducted, Hoskins, in both the first and second editions of his book, tracks the historical development and cultural adoption of 3D printing technology within the arts and crafts industry. His work is significant not only regarding how artists have made use of new technology in multiple disciplines but also for including a considered chapter within each edition on the uptake of 3D printing within the stop-motion animation industry. Although understandably limited, as only one of many examples in the book, it remains significant due to its contextualisation of animation into the broader topic of 3D printing. In particular, the updated second edition is far more reflective on the use of 3D printing in the often-underrepresented medium of animation compared to other books on the subject of 3D printing in art, craft, and industrial design.
Various papers by Bharoto Yekti (2015, 2017a, 2017b & 2020)
Regarding practical engagement with technical skills and visual considerations raised by 3D printing in stop-motion production, Bharoto Yekti—a lecturer in animation, film, and television at the Universitas Multimedia Nusantara, in Indonesia—is a notable example. He has written multiple papers that reflect on his own practical and analytical research exploring 3D printed puppet fabrication. In “Study of Laika’s facial expression mechanism system for stop-motion animation puppet through knock-down strategies on home-scaled 3D printer” (Yekti, 2017b)

[4] Although I found no prior PhD thesis or study that referenced or specifically examined the advent of 3D printing as it related to stop-motion animation production, a range of theses (from a broad array of artistic and practice-based/led disciplines) aided in the development of methodology and/or structure of this thesis. The most useful have been those written by Dr Sam Moore (2015), Dr Steve Henderson (2017), Dr Peter McCallion (2017), Dr Michaela French (2020) and, in particular, Dr Paul Laidler (2011), whose clear examination and thorough exploration of the subject of Collaborative Digital and Wide Format Printing provided a strong example of the thesis structure and participatory research.

Yekti recreated LAIKA’s eye and face registration system using cheaper desktop printers. Yekti also wrote two papers looking at the visual potential and qualities of 3D printing within stop-motion production: “Comparative aesthetic study between three-dimensional (3D) stop-motion animation and 3D computer graphic animation: Towards physicality and tactility, perfection and imperfection” (2015), which deciphers the difference between the two often disparate animation forms of stop-motion and CGI; and “Visual tactility of 3D printing utilization in stop motion animation” (2017a), in which he considers the potential of material tactility, the charm of ‘imperfection’, and human intervention between two early examples of fully 3D printed replacement sequences, *Bears on Stairs* (2014) by Blue Zoo/DBLG and *Unbox Yourself* (2014) by Georg Warga/Goodstein. His most recent papers include “Character design for 3D printed zoetrope visual style and character designs printability” (2020), which looks at the constraints of character design when working with 3D printing. Yekti often conducts research with students, using low-cost desktop printers, and due to their short form and technical focus, his papers offered an initial foundation for further exploration.
“A system for efficient 3D printed stop-motion face animation” by Rinat Abdrashitov, Alec Jacobson and Karan Singh (2019)
Researchers Abdrashitov, Jacobson and Singh created a semi-automated system for efficient replacement faces, thus allowing for optimization of printed outcomes by reducing deformation and the number of printed pieces, seeking to reduce the time and cost of production. This is a novel idea that if required would probably prove useful to those looking to reduce the number of printed parts, especially if the character typology were simple. The simplification of the ‘issues’ of stop-motion shows a lack of understanding of the art of stop-motion. For those for whom this system would be useful, the length and/or complexity of their project would most likely negate the need for such a system. For those whose project is long and complex enough to warrant such a system, they are likely seeking a high level of nuance in the film which would also negate this system use. No further research on this subject seems to have been conducted by any of the researchers subsequently.
***Stop Motion Filmmaking: The Complete Guide to Fabrication and Animation* by Christopher Walsh (2019)**
This recent how-to guide to stop-motion creation offers a chapter focused on creating 3D printed replacement mouths. It introduces the ways in which 3D printing can be used and how to take CG models through to the printed part, as well as a step-by-step tutorial for developing

a simple mouth replacement system. Although used in the creation of one specific replacement element it offers a straightforward introduction for those looking to create 3D parts for print. This is followed by an interview with special effects and 3D printing artist Daniel Baker, which contains further practical considerations and other potential avenues of exploration.
Various art of/behind the scene books and commercial making of videos
There has been increased interest in the art and process that goes into the making of large animation productions. As such, large glossy 'art of' books and high production value documentary-like commentary are part of many large-scale animation productions, from which much secondary research and both quantitative (numerical, technical) and qualitative (interviews and reflective writing) data can be extracted. As the leader within the development of 3D printed animation, LAIKA's Art of Books have offered valuable information that has aided in understanding much of the process. However, not every studio is so open; as noted by Nicole Evans, "[t]he main factor that separates this form of video evidence is its formal nature, its focus on the commercial positivity of the films or commercial property" (Evans, 2010:589). It is important to view these materials as being developed as promotional and consumable trivia-based documents for mass consumption, which in turn means certain factoids and process should be verified as much as possible and the researcher must remain vigilant to falsified information or simplifications of the process to appear 'slick' to the audience.
"The Evolution of Stop-motion Animation Technique Through 120 Years of Technological Innovations" by Vincenzo Maselli (2018)
Maselli has also conducted research in the field of Puppet Animation, with a focus on the material of the medium. In this short historic paper, he catalogues various technological innovations that have been used throughout the last 120 years of stop-motion animation production. He cites the use of 3D printing as "a useful tool for the development of replacement animation" but one that "relies upon the intervention of digital technologies as a relevant part of the manufacturing process itself" (2018). Maselli outlines the initial development of the technology, citing many of the sources I've stated above, as well as discussing its uptake within various studios and modes of animation production, and also referencing my own 2018 conference paper "The changing face of replacement animation: How looking to the past can revolutionise the future of stop-motion animation", delivered at the

SAS conference hosted at Concordia University in Montreal.
***Puppetry, Puppet Animation and the Digital Age* by Rolf Giesen (2019)**
A short book on the development of puppets and puppet animation since its origins, with a focus on its continued use. This book serves as an introduction to puppet animation in the modern age, briefly acknowledging major changes in the medium—with some minor mention of 3D printing, LAIKA, and the use of digital technology.
***Coraline: A Closer Look at Studio LAIKA's Stop-motion Witchcraft* edited by Mihaela Mihailova (2021)**
This collection features multiple essays by various respected researchers. Although this book did not guide my study—as it was published after my research stage and toward the end of my writing up stage—its central focus on the first stop-motion feature film to use 3D printing for replacement animation made its presence in my thesis a welcome addition. Multiple chapters reflect elements of my own study by validating many of the secondary resources and documents I have used, as well as offering alternative reading and viewpoints. The collection highlights the significance of LAIKA and their use of 3D printing as contributing to stop-motion history, both through *Coraline* and LAIKA's subsequent films.

[*Table 2*. Previous Research]

1.8 Structure and Summary of Following Chapters

This thesis guides the reader through the adoption and various changes 3D printing as a technology within the animation medium has undergone. In this introduction chapter—hereafter referred to as chapter 1—I have outlined the parameters, aim, and objectives of the study, the research design, the effect of COVID-19 on this study, the ethical considerations, an overview of the previous research in this subject, and the structure of the following chapters. Table 3 summarises each chapter as well as highlights which objectives they each explore. After chapter 2—which consists of a broader visual and contextual review of the history, development and subsequent uptake of 3D printing and other digital tools in the animation industry—the rest of the thesis can be seen as comprising of three interconnected sections reflecting on the main theoretical concepts at the heart of the study. Section 1 begins with chapter 3 and looks at the role of skill and digital craft that the use of 3D print elicits; this is practically explored in the long-form pilot study documented in chapter 4. Section 2 starts at chapter 5 and defines authorship in film and animation before uncovering the effect 3D printing has had on the authorial claim of various practitioners, which are explored further through a collaborative case study documented in chapter 6. Finally, section 3 starts at chapter 7 and explores the aesthetic potential 3D printing affords the visual quality of animation, as well as how this can work toward a narrative and emotive coherency within animation production; one such potential is explored in the final collaborative case study documented in chapter 8.

Chapter 2. Stop-Motion and its Relationship with Technology	
Chapter 2 reflects the broader historic, visual, and contextual review of the development and subsequent uptake of 3D printing in the animation industry. It also discusses other digital production and fabrication tools that have been used in animation. *The focus of this chapter is to argue against the idea that stop-motion is a purely analogue or handmade process when in fact it utilises many digital tools in uniquely creative ways.*	***Objectives met:*** Survey current practitioners using 3D printing within stop-motion animation. Plot the historical development that led to the use of 3D printing in stop-motion.
Chapter 3. Digital Craft Skills in a Hand-Made Medium	
Chapter 3 looks at the definition of skill and the role of digital craft, what skills and techniques are needed to create work with 3D printing, and how this has been adopted into various elements of the production pipeline of puppet and stop-motion creation. It includes interviews with model makers working in the industry and looks at how the technology is aiding and diversifying the ways they work, what advantages 3D printing offers, and the realities of the process within the industry. The chapter also examines why the use of 3D printing has increased and how it is used in a variety of ways; discusses the benefits and drawbacks of it from a practical perspective and the skills required to use it; and surveys the ways that 3D printing has been used as a tool or for the creation of tools both inside and outside the puppet	***Objectives met:*** Survey current practitioners using 3D printing within stop-motion animation. Discuss with practitioners the issues surrounding **craft skill**, authorship and aesthetic potential **when using 3D printing** and **other digital fabrication tools.**

fabrication process. *The focus of this chapter is to define 3D printing as purely a tool in the stop-motion arsenal and determine the increased level of skill required to use it.*	Use **interviews** and **case studies** to identify strengths and weaknesses of the use of 3D printing both visually and mechanically.
Chapter 4. Long-Form Pilot Study: Material and Joint Design	
Chapter 4 documents a long-form pilot study, comprising a material study and a summary of the development of requisite skills to use the technology in order to conduct this practice-led research. The pilot study was created to learn all parts of the 3D printing pipeline—from design, to slicing, to printing, maintaining a machine, and preparing files, as well as liaising with bureaus/outside companies. The material study produced a wide range of physical samples, both to further my own understanding and to aid in the development of the subsequent case studies. These materials were reviewed for strength, stretch, surface finish and potential for further investigation. *The focus of this chapter is to give further practical knowledge and insight into the process of developing 3D printed materials for use in animation, and to highlight the strengths and weaknesses of various materials, 3D printing processes, and techniques.*	***Objectives met:*** Use interviews and **case studies** to identify **strengths** and **weaknesses of** the use of **3D printing** both **visually** and **mechanically**. Develop these themes and **experiments** into my **practical work/artefacts.**
Chapter 5. Authorship and Labour	
Chapter 5 explores the critical understanding of levels of authorship within film and animation production, and what effect this has had on those who have an authorial claim within the highly collaborative process of industrial	***Objectives met:*** Discuss with practitioners the issues surrounding craft skill, **authorship** and aesthetic

animation. Focus has been placed on animators and those engaged with the 3D printing replacement process, by acknowledging the authorial and creative dichotomies at play within the ever-increasing complexity of the process. This is concluded with a proposal regarding how ultra-auteur practitioners may be able to gain further authorial control as well as develop creative potential through the use of 3D printing, which is explored further in the subsequent chapter. *The focus of this chapter is on how the use of 3D printing has affected the production process for practitioners within the stop-motion industry. It aims to dispel the notion that 3D printing is somehow easier or leads to a reduction in jobs, as it is, in fact, adding complexity and thus more jobs, both in scale and within new departments that have been created due to the adoption of 3D printing. There is also additional attention placed on the use of 3D printing for those working on a smaller scale, or at the independent end of the animation industry.*	potential when **using 3D printing and other digital fabrication tools.** Discuss with practitioners the issues surrounding creativity and **authorship** when using digital fabrication tools.
Chapter 6. Case Study: Auteur Filmmaker Eye Mechanism—*SHACKLE*	
Chapter 6 documents the production of a case study with filmmaker Ainslie Henderson, in the collaborative designing and manufacturing of a set of bespoke eye mechanics for use in puppet generation, for his BFI funded short film *SHACKLE*. Positioned as fabricator and researcher within the study, I aided in the CAD modelling, as well as advised on the appropriate 3D printing process and materials for the look, finish, and pricing of the project. *The primary aim of the study was to create functional internal mechanics using 3D printing to give further authorial control to the collaborative filmmaker, as well as to observe and log the iterative cycles of action research in the development of the eye*	***Objectives met:*** Use interviews and **case studies** to identify **strengths** and **weaknesses of** the use of **3D printing** both **visually** and **mechanically**. Develop these themes and **experiments** into my **practical work/artefacts.** Discuss with practitioners the

mechanism, while gathering further insight into the benefits and drawbacks of the technology when used for ultra-auteur production.	issues surrounding **craft skill**, **authorship** and **aesthetic potential** when **using 3D printing** and other digital fabrication tools**.**
Chapter 7. Aesthetic Potential of 3D Printed Animation	
Chapter 7 analyses the aesthetic potential 3D printing affords the visual quality of stop-motion animation from multiple theoretic perspectives, using key examples to examine how the technology enabled visual, narrative, and emotive coherency within each animation production. This is achieved through close textual analysis of secondary documents as well as interviews with those involved in the film's production. This chapter also highlights several potential areas for further exploration regarding the future of stop-motion production, both with 3D printing and other facial animation processes. *The focus of this chapter is to review how 3D printing has changed, altered, or added to the visual potential of stop-motion through examples that explore both the rationale and potential as an artistic tool. The aim of this chapter is to discuss 3D printing's aesthetic potential and question its ability to blur the lines of technology, as well as to argue for a more low-tech approach to better utilise the natural material quality of the printer technology for either visual, metaphoric, or other narrative reasons.*	***Objectives met:*** Plot the historical development that led to the use of 3D printing in stop-motion. Survey current practitioners using 3D printing within stop-motion animation. Discuss with practitioners the issues surrounding craft skill, authorship and **aesthetic potential** when **using 3D printing** and **other digital fabrication tools.** Use **interviews** and **case studies to identify strengths and weaknesses of the use of 3D printing** both **visually** and mechanically.
Chapter 8. Case Study: Novel Film—*Crafty Witch*	

Chapter 8 discusses the development of a short, animated film using a novel approach to design and process. In this case study I am in the position of filmmaker, animator, and fabricator, combining the skills and experience developed throughout the study to create a film that explores the various theoretical ideas and considerations I have laid out in the previous chapters, in collaboration with 2D animator Sam Shaw to create a hybrid approach to story generation and visual exploration. This chapter is accompanied by a 1-minute microfilm and making-of video, which can be found in the additional materials of this thesis. *The focus of this chapter is on the reflectivity and consolidation in producing a film that demonstrates the potential of 3D printing as a unique tool, capable of creating purposeful mark making strategies that can be read as unique material qualities implicit through the machine and its materials.*	***Objectives met:*** Use interviews and **case studies to identify strengths and weaknesses of the use of 3D printing both visually and mechanically.** Develop these themes and **experiments** into my **practical work/artefacts.** Discuss with practitioners the issues surrounding **craft skill**, **authorship** and **aesthetic potential** when **using 3D printing** and other digital fabrication tools**.**
Chapter 9. Conclusion	
The final chapter will amalgamate all findings and highlight the contribution to knowledge uncovered through the study. It will also suggest areas for further investigation following the study before offering final conclusive remarks regarding the research and the work created through it.	***Aims met:*** To investigate the impact of 3D printing on the visual identity of stop-motion To use 3D printing to create novel puppet manufacturing processes.

[*Table 3*. Thesis Chapter Summary]

Chapter 2. Stop-Motion and its Relationship with Technology

Stop-motion, in its simplest definition, is the manipulation or alteration of any physical object, in sequence and captured frame-by-frame, to create the illusion of movement. Its discovery is most often credited to Georges Méliès who in 1896 "happened upon the phenomenon" of "stop-action" whilst filming *Place de l'Opéra* (Harryhausen & Dalton, 2008:38–9). An earlier example from 1895 by Alfred Clarke, *The Execution of Mary Queen of Scots*, used trick-photography to animate the decapitation of Queen Mary (Furniss, 2017:29).[5] Animation has always sought out innovations and new technology to help solve problems, ease production, or create novel visuals, such as with plasticine, for example. Invented by William Harbutt in 1897, the material was revolutionary; unlike clay, it did not dry out or harden over time, as it combined both wax and oil (Frierson, 1994). Plasticine is commonly used for characters like Morph and Gumby, as well as for facial animation by sculpting changes in facial expression between frames, as seen in early Aardman shorts such as *Adam* (1992) and *A Grand Day Out* (1989). It is still used in productions today, such as *Chuck Steel: Night of the Trampires* (2018). Stop-motion is used in commercials, series, and independent, experimental, short-form, and feature films. For a large and influential period of its history, stop-motion was used for special effect in live-action films; early examples include Wills H. O'Brien's *The Lost World* (1925), *King Kong* (1933), Ray Harryhausen's *Clash of the Titans* (1981), and *The Golden Voyage of Sinbad* (1973), all of which have become synonymous with early creature films. This tradition carried on well into the late '80s and early '90s, alongside puppetry and animatronics, before the advent of digital VFX (visual effects). The use of CGI for VFX could have rendered stop-motion and physical puppets obsolete, but this is far from the case. The increased availability and affordability of digital technology has in fact aided the ease and speed of many stop-motion productions (Comiskey, 2015).

Before the use of "video-taps" and digital capture software, stop-motion animators worked effectively blind to the images taken previously in a sequence, relying on the use of surface gauges to track incremental changes or on their own visual and motor memory; Holman refers to this as the "Zeno's Paradox", stating that "at the time of filming the puppets, previous actions exist only in an animator's memory and as an invisible latent image in the film" (Holman,

[5] *The Humpty Dumpty Circus* (1897–98) by Albert E. Smith and James Stuart Blackton is widely considered the first intentionally filmed piece of trick photography (Giesen, 2019:99) that contained the essence of what stop-motion is recognised as being today (Harryhausen & Dalton, 2008:39).

1975:50–51). The inability to see shots as they progressed caused multiple issues; the accidental shifting or settling of sets, props, and puppets often went unnoticed by the animator on set, causing potentially months of work to become unusable, as the film needed to be processed in a laboratory before any errors or problems with the day's work could be seen (Shaw, 2004:13).[6] This, along with the capability of the individual animator, the complexity of performance, scale and type of puppet being used, accounts for the varying quality in early animated films. This is not to say that the quality of older animations was of a low standard, but perhaps more acutely stylised in its movement. The use of video-taps on *The Nightmare Before Christmas* (1990) provided animators with a safety net, meaning they no longer had to rely on intuition and memory alone (Comiskey, 2015:51). This innovation revolutionised production, allowing for easier reviewing and processing, but also permitted a wider range of people to work with stop-motion, rather than just a determined few with large amounts of money (Shaw, 2004:13). Software and hardware have become more affordable, allowing anyone with a budding interest to try the process on computers, laptops, tablets, and smartphones. Some practitioners, however, prefer the intuition, spontaneity, and flow of animating without frame-capture software. The ability to continually tweak performances made possible by digital processes will be discussed further in chapter 5 regarding authorship in animation production.

The advent of digital cameras and photography was also vital for the future of stop-motion production. Digital cameras, first used on Tim Burton's *Corpse Bride* (2005), offered an increased sense of freedom on set; the low cost, small size, and ability to work within the confines of a stop-motion set was a hugely influential innovation for stop-motion production. So much so that studios like Aardman shelved their fleet of thirty-five custom-fitted Mitchell cameras, replacing them with digital Canon EOS-IDs (Comiskey, 2015). Digital photography, in combination with the internet, also allowed for satellite micro-managing, as documented through Wes Anderson's 2009 film *Fantastic Mr. Fox*. A specialist setup was created to allow Anderson access from his home in Paris to real-time pictures shot on stages in England, making it possible for him to direct almost the entire film away from the studio that was creating it (Brody, 2009). Motion control allowed more complex camera movement and tracking during a shot; a robotic arm can digitally move the camera in any position and even be programmed to create the exact same movement multiple times for numerous takes (Shaw, 2008:182). Although

[6] Aardman founder David Sproxton saw a demonstration of a video-tap technology known as PVR (Perception Video recorder) in 1990/1, at the Cardiff Animation Festival. This system was eventually released as the "Animate" system (Shaw, 2004:13).

adding complexity to both planning and animating, this allows for a significant increase in cinematic camera moves within the stop-motion process. Motion control also offers a unique solution for complicated rigs, set pieces and unusual puppets, as exemplified with the underwater monster in *Kubo and the Two Strings* (2016). Controlled using a bowling ball that was tracked with sensors, motor and cable operations enabled animators to manipulate the puppet without physically touching it (io9,2016), speeding up production and allowing the animators to create small flowing movements to mimic the undersea location of the puppet. In the same film, a 16-foot skeleton puppet also used a mechanical computer-controlled rigging system, with cabled marionette style limbs. This allowed a tremendous size and weight to be moved with the same level of precision as its two-foot counterpart (BBC Click, 2016).

Lighting control rigs also permit greater cinematic potential, creating consistency over multiple setups, and when used in conjunction with motion control, lighting can be changed incrementally over the progression of a shot, using a computerised master light board (Comiskey, 2015:48–9). The use of playback tools, motion control and digital DSLR cameras allowed for more complex camera moves, nuanced performance and the cinematic dynamics of 'live-action' or, more pertinently, CG animation/VFX (Shadbolt 2021:124). They also allowed for the use of stereoscopic 3D (S-3D) filming within stop-motion, with *Coraline* (2009) being the first (Denison, 2021:163). Although often seen as a gimmick within film distribution, S-3D offers stop-motion films added depth and textural dimension (Walker, 2009:29; Shadbolt, 2021:129) and can also be used as a poignant narrative device, as seen in *Coraline,* to further separate the two worlds within the film (Cook, 2021:34; Mihailova, 2021a:5).

Computer Generated Imagery (CGI) can be used to create VFX such as explosions, smoke, rain, large vistas, or bodies of water within a stop-motion production. Aardman's *The Pirates! In an Adventure with Scientists!* (2012) and LAIKA's *Kubo and the Two Strings* (2016) both used CGI to create an expansive sea, something that would be extremely difficult to craft by hand (Montgomery, 2016; Soyer, 2012; Comiskey, 2015:55–6). These effects are often stylised to mimic the physical handcrafted world they are in. Digital set extension and composited backgrounds also add depth and increased visual spectacle to a film. The predominant use for CGI, however, is to digitally remove rigs in post-production, making possible gravity-defying shots of puppets and set components mid-frame. This is also present in the removal of seams on the face or neck of characters when using replacements. Some filmmakers, however, prefer to use handmade, physical special effects instead of digital technology. Wes Anderson is an advocate of a mixed material approach to special effects in his films, often deploying complex techniques to create smoke, fire and water using materials such as cotton, plastic, wood, paper, and resin cast replacements, to produce in-camera effects that create a distinctly handmade visual style (Wilford & Stevenson, 2018:125).

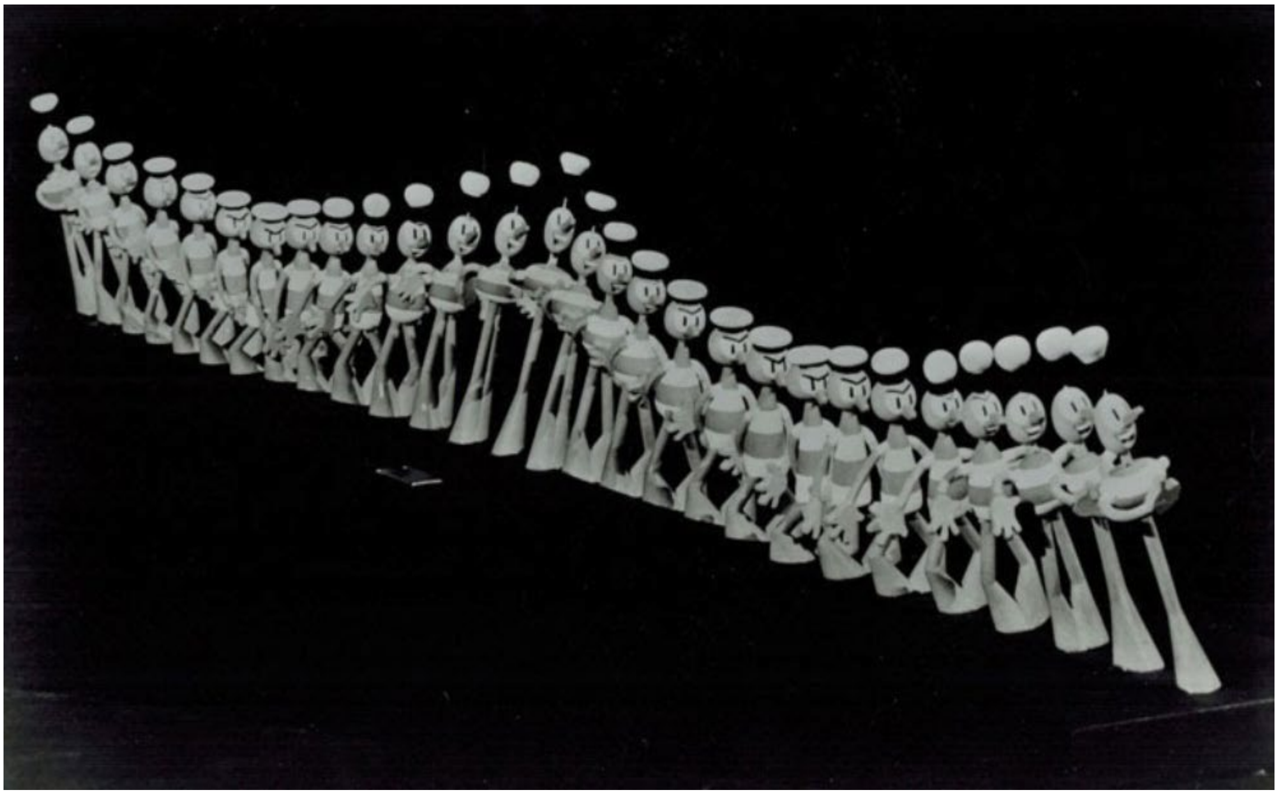
This idea of technology leading innovation in stop-motion animation is not new and has driven many industrial and visual revolutions. The histories of both stop-motion and 3D printing are rich, although it is only in the last couple of decades that these two methods of creating work have begun to develop; in both instances, the potential is far from being fully discovered. With advancements in both areas continually developing, the options are ever-growing. Moving forward I will draw parallels between historical techniques and recent developments in the use of 3D printing, overviewing what has led to the development of 3D printing within the stop-motion animation industry, and the subsequent key uses in industry. From an academic perspective, there has never been a better time to observe the relationship between 3D printing and stop-motion, as the most obvious ideas have already been explored. It is now time to apply rigorous research and scrutiny to the aesthetic and mechanical potential of this technology within stop-motion.

2.1 What is Replacement Animation?

Replacement animation is used when a series of different models—often one per frame—create the illusion of movement instead of moving a puppet's body or limb individually, frame by frame (Pettigrew, 1956). It is an animation technique used within puppet, clay, and other variation of stop-motion processes, in which an object is swapped out between shots. Replacement animation can be used in multiple ways but is primarily employed for facial animation—something that can be documented as early as 1917 in Howard S. Moss's *MoToy* comedies (Priebe, 2007:138–9).[7] Full-body replacements were largely popularised by Hungarian animator George Pal in his *Puppetoon* series; Pal meticulously designed each frame before they were carved, painted, constructed and then finally animated shot by shot (Harryhausen & Dalton, 2008:152). This technique is used to apply fluid and high impact extreme poses to a performance, as it does not rely on the mechanics of the internal armature to be able to animate the character or object. This style was developed by Pal in the 1930s (Bendazzi, 2016:166–7)

[7] Replacements were likely inspired by the process behind hand-drawn animation, where a newly drawn frame is photographed in sequence (Priebe, 2007:139).

and is akin to the "rubber hose" animation style popular in the 1920s [Figure 2]. "Rubber hose" animation is more often seen in classic, hand-drawn animation such as *Steamboat Willie* (1928), in which a character seemingly has no angular joints and displays loose, "rubbery" body movements (Furniss, 2017:48).



[*Figure 2*. Pal, G. *The Philips Broadcast* (1938). Copyright Philips Company Archives]

Using replacement animation to visualise morphs and transformations is evident in all forms of stop-motion. Pioneering animator Lotte Reiniger would replace paper puppets between frames to create the illusion of a transformation, as seen in the transition of the frog puppet to a prince in *The Frog Prince (*1954). The technique is also used in clay animation, like *Morph* or *Pingu* (Purves, 2010:98-9) to reduce the workload of the animator on set, as seen in the creation of multiple legs for *Morph*: *Box of Tricks* (2014) [Figure 3].[8] However, Pal remains the principal reference for the early production of replacement animation, possibly due to his Academy

[8] Replacements were also used in Morph episode "Remote" (2018) in which the character of Chas changes colours between frames (Morph, 2018).

Award for the “Development of Animation Techniques” in 1943 (Harryhausen & Dalton, 2008:152).[9]

[*Figure 3*. *Box of Tricks* (2014). © Aardman Animations 2014]

Replacements can be used in many ways including bodies, limbs, heads, facial features, or a combination of all of these. It can also be used for object animation, props and set components. Replacement is most widely used as a way of creating easy lip sync (Purves, 2008:134). This can be in the form of plates [Figure 4], stick-on 2D mouths or more unique examples, such as in the recent Aardman commercial for DFS in the UK, in which they used digitally embroidered replacement mouths (Arena Illustration, 2016). As an alternative to replacements, paddled mouths within geared heads offer small, nuanced changes to mouth shapes (Salisbury, 2005:47–51). However, replacements offer greater exaggerated expressions and poses without the constraints of physical materials such as silicone, fur, or cloth as when using paddled mouths, or the slower process of sculpt-though with clay. This technique has never really been out of the animator’s tool kit and was used with great effect in films such as *The Nightmare*

[9] A knowing nod to Pal can be seen in the dancing mouse circus scene in *Coraline* (2009), in which multiple replacement mice are choreographed into hypnotic “animated cycles” or loops (Mihailova, 2021b:63; Torre, 2021:99–100).

Before Christmas (1993) and *James and the Giant Peach* (1996), as well as in multiple TV series and commercials (Purves, 2008:134–5).

[*Figure 4*. Cowley, L. *Boris-Noris* Mouth Replacement Plates (2017)]

2.2 The Advent of 3D Printed Replacements

It is widely accepted that LAIKA pioneered the use of 3D printing for stop-motion character animation for *Coraline* (2009) (Priebe, 2011:141; Roberts, 2012; Jaremko-Greenwold, 2015; Foutch, 2016; Karlin, 2016). This combination of innovation and artistry earned the heads of 3D printing at LAIKA, Brian McLean and Martin Meunier, the Scientific and Engineering Award at the 2016 Academy Awards (oscars.org, 2016). The idea may well have been simultaneously conceived within various companies and practitioners working in the industry at the time, as 3D printed fabrication was established as early as the 1980s, after the invention of stereolithography in 1983 by Chuck Hull of 3D Systems (3Dsystems.com, 2020). However, *Coraline* (2009) was certainly the first feature-length stop-motion film to use 3D printing. This was closely followed by the first short-form commercial use by Johnny Kelly for *Het Klokhuis* (*The Apple Core)* in 2010 [Figure 5], showing an apple undergoing multiple transformations using 3D printed replacements. As titles for a Dutch science television show, the mix of classical stop-motion techniques with innovative technology was a novel approach, showcasing the use of both modern and classical design (Ulloa, 2010). The accuracy and precision of 3D printing here allowed for merging of CGI and stop-motion animation.

[*Figure 5*. *Het Klokhuis* (2010). Copyright Johnny Kelly]

Since then, the use of 3D printing to revolutionise the replacement technique as well as other production processes has been widespread in commercials, features, and independent films (Torre, 2021:97). There are multiple advantages and stylistic opportunities available through 3D printed replacement; the examples below showcase the benefits and distinctive attributes 3D printed replacements can offer. These projects can largely be separated into two types of replacements, either a) whole puppet, or b) head or face. 3D printing is also used in alternative and unique ways including experimental film, armatures, tool creation, moulds, and cores, which is discussed in chapter 3(3.3).

2.2.1 Replacing the Whole Puppet

Bear on Stairs (2014), developed by animators at Blue Zoo for the DBLG agency, is often used as an example of the application and beauty of low poly CGI animation replicated through 3D printing [Figure 6]. This film was made to promote the creative possibilities of combining 3D printing and stop motion, by demonstrating new considerations in regard to style and blurring the line between animation forms to create new hybrid possibilities.

[*Figure 6*. Blue Zoo, *Bear on Stairs* (2014). Copyright DBLG]

This technique was also used in Eran Amir's short film *Run Baby Run* (Amir, 2016), which uses a 3D printed run cycle photographed in a real-world environment. The surreal visuals struck a chord online and went on to win the Cannes Lions Young Director Award in 2016. Amir is an experimental animator who uses multiple techniques to create unusual and engaging short films, music videos and commercials. The film creatively demonstrates the potential of animating within real environments; the visible shift in weather conditions is kept to a minimum due to the relatively fast shooting potential that replacement offers. 3D printing also offers bespoke sculpting and physical models to a new range of filmmakers, as to sculpt, mould and cast such a character traditionally would have required significant additional skills, tools, materials, and time. 3D printing can be used effectively for independent filmmaking, to reduce time and elevate certain technical requirements for low to no budget productions, as well as opening up new possibilities for those with a CG skill set.

Job, Joris and Marieke's 2015 project *Freeze!* was an installation that visualised the stop motion process using physical 3D printed models:

> Freeze! is a frozen movement, each frame of the animation has been printed on a 3D printer. It explains the principles of animation without a single bit moving. This installation was made for the exhibition MOVE ON…! by Kunsthal KAdE in Amersfoort. (jobjorisenmarieke, 2015)

Similarly, their music video *Gravity* (2017) shows the layer lines, support framework and construction flaws in 3D printing. The decision not to remove or conceal the framework reflected the band's lyrics about unseen forces like gravity:

> We created mesmerising loops for three songs. Sometimes hidden forces obstruct us in our daily lives, and sometimes they seem to support us in what we do. The inspiration for these loops came from the 3D printing process. Branchlike structures are needed to print overhanging parts. These structures are meant to be broken away. But we thought these structures beautifully captured the theme of the songs. (jobjorisenmarieke, 2017)

This use of the support system as the normally discarded or hidden elements of 3D printing construction offers up an interesting area of study and investigation and is discussed further in chapter 7 (7.4).

Jack Cunningham's film *Proper*, for London based shirt company Tripl Stitched, "[mixed] old techniques with modern" to create "a unique insight into how the craft of making has evolved whilst still retaining traditional values and skills" (triplestitched.com, 2016), a similar ideology as in *The Apple Core* (2010), in which old and new techniques are married. The increased quality of *Proper* and its ability to produce a carved, hand finished look, shows the progress of 3D printing in the subsequent six years [Figure 7].

[*Figure 7*. *Proper* (2016). Copyright Jack Cunningham]

A novel approach to replacement is seen in the film *Transforming* by Mizuki Kawano, in which 3D printed replacement manicure sets are animated on a human hand, showcasing the potential for 3D printing to be used for alternative experimental processes [Figure 8].

[*Figure 8*. Kawano, M., *Transforming* (2015). Copyright TAIYO KIKAKU Co., Ltd]

Hello Play (2015), a music video by Greg Barth, uses replacements to visualise the melody and shape of the sound to create visual rhythm. The unique feature of both *Hello Play* and

Transforming (2015) is the lack of central character. Instead, these films demonstrate the potential for visualising concepts in alternative ways to CGI or VFX [Figure 9]. The benefits of developing visuals in-camera as opposed to digitally adding them in post-production is debatable, but the ability to manipulate the audience's perception with physical shadows, light, and printed textures could be explored further in future.

[*Figure 9*. *Hello Play* (2015). Copyright Greg Barth. Image used with thanks to Blinkink]

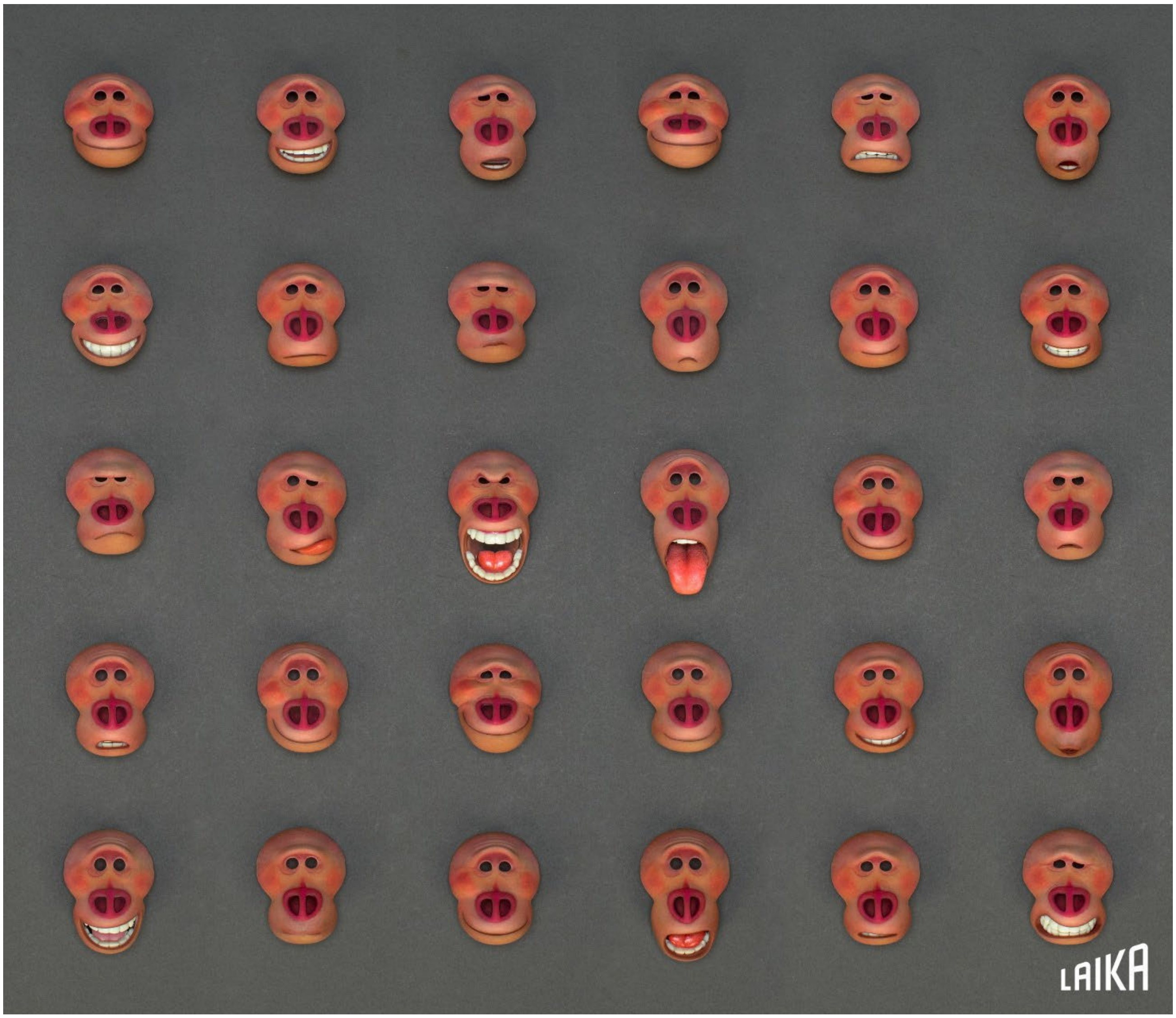
Chase Me (2015) by Gilles-Alexandre Deschaud is an independent music video that was created with the help of 3D printer developers Formlabs (chasemefilm.com, 2022). The film showcased the potential of Formlabs machines whilst also demonstrating the possibilities for CGI stop-motion hybridity within all areas of production [Figure 10]. The relatively simple film has an otherworldly quality, that exhibits the visible characteristics that 3D printed materials can bring regarding texture, shape, and form.

[*Figure 10*. *Chase Me* (2015). Copyright Gilles-Alexandre Deschaud]

Aardman also used 3D printing for the unique short film *Dot* (Sumo Science, 2014), featuring the world's smallest stop-motion character. The film was created for Nokia upon the development of the mobile microscope. The central character, standing 9mm tall and individually hand-painted, interacts with multiple found objects, such as real insects, buttons, and coins (Laboratory Equipment, 2010). This film shows the scalability of 3D printing for detailed miniatures, and the ability to have multiple scales of characters for different setups or scenes.

2.2.2 Replacing the Face or Head

Aardman developed their own pipeline for 3D printing facial replacement for *The Pirates! In an Adventure with Scientists!* (2012). Using Envision Tech printers due to their "ability to print in a flesh-coloured material, thus reducing the amount of painting" (Hoskins, 2015:126). *The Magic of Craft* (2016), created by Salon Alpin for Montblanc, designed geometric, sharp-angled 3D printed faces to create puppets that strike a balance between free artistic interpretation and the design of Montblanc products (Salonalpin.net, 2016). In the same year, specialist puppet fabrication studio Mackinnon & Saunders created *The Greatest Gift* (2016) for British supermarket chain Sainsbury's, directed by Sam Fell who had previously worked at LAIKA as co-director of *ParaNorman* (2012). The film was able to create a huge number of puppets and sets with incredible detail, producing “essentially a mini-film” within a commercial timeframe (Davies, 2016). This demonstrated how 3D printing can enhance character design and performance in a shorter amount of time than traditional puppet making.



[*Figure 11.* Multiple faces of Mr. Link from *Missing Link* (2019). Image used with Special Thanks to LAIKA Studios]

It is LAIKA, however, who have remained at the cutting edge of 3D printing development within stop-motion. For *ParaNorman* (2012), LAIKA produced intricate smear frames [Figure 12], for a scene in which a character is metamorphosising, allowing the puppet to interact with lighting and atmospherics on set as opposed to relying on digital effects in post-production. They also began embedding colour directly into printed faces. In 2014, LAIKA began to develop a greater sense of artistry and colour; they incorporated painterly strokes and tone into puppet faces for *The Boxtrolls* and in *Kubo and the Two Strings* (2017) and developed this further using Cuttlefish® technology. In 2019, they created bespoke faces for almost every frame for *Missing Link* (Cowley, 2019). A more in-depth discussion of their varying processes and use of 3D printing technology can be found in chapter 7 (7.3.1).

[*Figure 12*. Individual smear frames printed to create dynamic in-camera special effect for *ParaNorman* (2012). Image used with Special Thanks to LAIKA Studios]

Replacement masks remain one of the most discussed and widest uses of 3D printings within stop-motion animation. *Anomalisa* (2015) and short film *Bone Mother* (2018) offer a more distinct opportunity to discuss the aesthetic qualities 3D printing has to offer and are discussed further in chapter 7 (7.3.2 and 7.4).

2.3 Other Digital Fabrication Tools

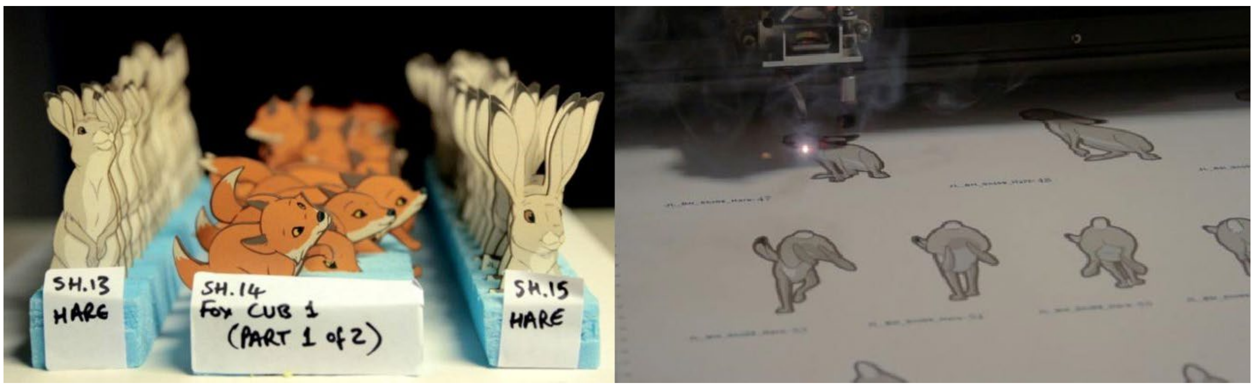
It is important to state at this stage that 3D printing is not the only digital fabrication tool being used by studios and practitioners in the animation industry today—far from it, in fact. Unlike live-action films that can shoot on location and make use of everyday objects, stop-motion requires every element that appears on screen to be created in miniature using an extensive range of tools and materials. The digitalisation of common tools can offer added accuracy and efficiency. The variety of visual styles employed for puppets and the worlds they inhabit often requires specialised technology; one such example is the use of digital embroidery for replacement mouths as seen in Aardman's DFS commercial (mentioned in section 2.1), to match the fabric world. The same technology can also be used for costume details. A more unusual application is the creation of animated sequences straight from the needle, such as in music video *Tharsis Sleeps* (Random Acts, 2017) and the BBC World Cup ident (2018), both directed by Nicos Livesey, which recreated digital 2D animation through digital embroidery and shot under camera to create vibrant animated tapestries, reminiscent of band and sport patches (The Drum, 2018).

[*Figure 13.* Livesey, N., *BBC World Cup: The Tapestry* (2018). Image used with thanks to Blinkink]

Laser cutting is one of the most used digital fabrication tools within stop-motion, primarily in the creation of large set pieces and props. As Chris Finnegan of Screen Novelties Studio explains:

> [We use] laser cutting extensively, […] [it] is very helpful for set details, for instance, one time we built this kung-fu dojo with […] ornaments and to be able to laser cut all of that lacework and scrollwork to apply to the set is really a nice short cut to have.[10]

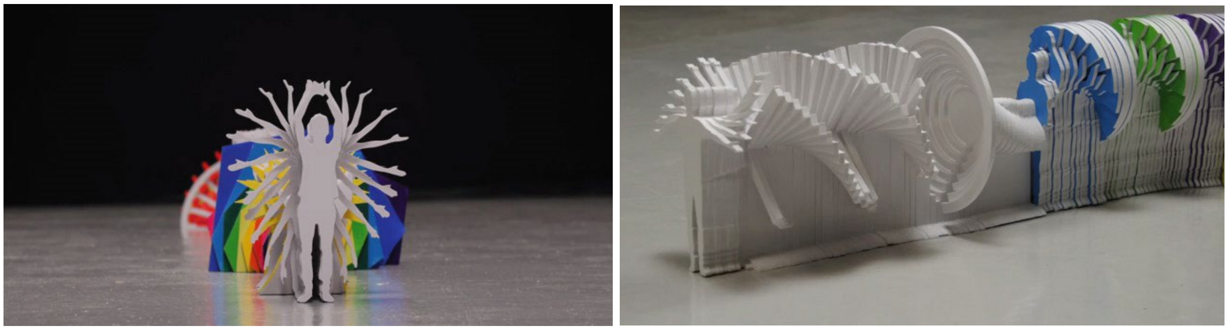
Elliot Dear and Yves Geleyn's John Lewis Christmas commercial *The Bear and the Hare* (2013) turned 2D animation sequences into almost 4000 laser cut frames, which were replaced frame by frame on a three-dimensional set to create a visually intriguing hybrid film (*Blink*, 2013).



[*Figures 14.1-2.* Dear, E., and Geleyn, Y., Laser cut frames from *The Bear and The Hare* (2013). Image used with thanks to Blinkink]

Similarly, *Katachi* (2013), directed by Kasia Kijek and Przemek Adamski, used approximately 2,000 computer-controlled cut PVC plates, layered in front of one another and photographed between each frame. The word "Katachi" means "shape", which is represented by the physical and visual ghosting of each individual animated silhouettes and the new shape being created by the meticulously aligned cut-outs. A+C studio used laser-cutting to make bespoke tools, in the form of stencils depicting a simple animated sequence of plastic pollution. These were used to sprinkle chocolate powder on milk foam in reusable cups for *World Ocean Day* (2019).

[10] Interview with Chris Finnegan, personal correspondence, 30th July 2019.



[*Figures 15.1-2.* (2013). Copyright Kasia Kijek and Przemek Adamski]

An often overlooked but commonly used digital tool is the humble ink printer. Due to the small scale and bespoke requirements of puppet fabrics and costumes, inkjet printers are used to print perfectly scaled miniature patterns directly onto fabric. This is necessary as patterns and even the weave size of fabrics can look inaccurate when seen magnified on the large screen (Wilford & Stevenson, 2018:110). Some practitioners turn to image software to create uniquely hand-rendered fabric patterns to fit the look of the world. As Janette Goody, director of the short film *The Story of Percival Pilts* (2015), explains:

> I couldn't find anything that was right in fabric shops, so I ended up doing all the materials with the combination of making my own designs in Photoshop, printing them out onto quilter's fabric, then using an awful lot of dye and tea and various other things to age them and make them look right. (Cowley, 2016)

This method of creating personalised fabric was also discussed during my interview with Andy Gent, the owner of Arch model studio in London, who has worked on multiple short, commercial, and feature productions, including *Isle of Dogs* (2018), directed by Wes Anderson:

> On *Isle of Dogs*, there was an amazing process to get the print work on to fabric which really changed our ability to make beautiful traditional [fabric] which was very ornate and intricate. Creating a textile pattern to the right scale for the puppet and then printing them out.[11]

This overview of stop-motion's relationship with technology demonstrates that both historically and currently the uptake of new materials and technology within stop-motion is far from new. The perception that stop-motion as an art form is somehow technophobic or remains fully

[11] Interview with Andy Gent, personal communication, 1st January 2020.

handmade—as is often believed—is largely untrue. However, the idea of the skilled craftsperson and the hand-touched aesthetic remains very much present, both in the films themselves and in the way they are presented and discussed through media, critical discussion, and academic readings. Moving forward, I will predominantly be discussing 3D printing as both a tool and a subject within my study, as I believe it had and continues to have a larger disruptive effect on the industry and thus offers a wide range of theoretical discussion points, such as the technological paradigm between the creative potential and critical discussion around the culture of stop-motion production.

Chapter 3. Digital Craft Skills in a Hand-Made Medium

In the previous chapter we noted that the use of digital technology in stop motion is neither unusual nor new. However, throughout the history of the medium, a concerted effort has been made to maintain the handmade aesthetic; how important this is from an aesthetic perspective is discussed in chapter 7. In this chapter, we will explore how 3D printing is being used both as a tool and as a method of creating tools for animation production. This will be done by looking at how placing heavy emphasis on skill informs an understanding of craft, as well as addressing how 3D printing has altered the puppet-making/fabrication process and the advantages it offers to digital craftspeople. It will also cover technical and mechanical skills practitioners may need to engage with the technology. This will lead to an examination of the available materials and technology explored during the study, bringing together the dichotomy of analogue and digital by the rather elusive connective term 'craft', itself loaded with many applications and interpretations. Here I will be using it as a term that denotes skill learnt in a dedicated manner that incorporates both the analogue hand and the digital tool.

3.1 Crafted Animation: What is Craft in Animation?

Alexander Mackendrick was a highly influential director and educator who became the first dean of the California Arts Institute. Although he spent much of his life around artists, he never felt comfortable calling himself one, instead choosing to identify as a "professional". As Paul Cronin notes, to Mackendrick the work of a director was a "craft […] that could be learned by anyone willing to undergo the necessary rigorous training". Skills considered paramount to becoming an "efficient storyteller" (Mackendrick & Cronin, 2003:xviii–xix) are even more expansive in stop-motion, which is defined by its ability to combine any and all craft skills into one cohesive form with its reliance on the physical, making use of every perceivable material, technology, and skill in the pursuit of that which is novel. Multi-skilled practitioners are required not only to know how to use multiple tools, materials, and techniques, but also how to adapt them to work in miniature. A new tool or skill adds further value to the modelmaker, animator, or filmmaker's arsenal, which in turn offers potential new aesthetic or production opportunities. Modelmakers are artisanal craftspeople who, rather than accruing knowledge over years to become masters at one particular mode of work, are known to 'hack' or interpret skills and techniques gathered largely by themselves (or otherwise through ad hoc training via art school, how-to books/videos, or on-the-job via projects and studios) to create masterful objects.[12] It is a career that can be simultaneously repetitive, slow, varied, and fast-paced. This in part is what makes stop-motion such a hard subject to study, as it sits between many different disciplines with no singular, consistent element throughout all works.

The term 'craft' has a number of considerations and meanings. As Caroline Ruddell and Paul Ward outline in *The Crafty Animator* (2019), 'craft' has been debated and theorised, both as a way of making and a formation of intellectual pursuit. It has been seen as "supplemental", subservient, and sub-sectional in relation to or beside "art" (Adamson, 2007:14–32), has "function" in political ideologies, such as industrialisation (Morris, 1888; Cooley, 1980), cultural value (Ruskin, 1851–83), wellbeing (Sennett, 2008), and feminist or gender biases that haunt craft practice (Adamson, 2007; Husbands, 2019). A recurring component is skill and the mastery of it, particularly regarding "digital craft", which will be the focus of this chapter (Ruddell & Ward, 2019:6–14). Sociologist and cultural studies writer Richard Sennett defines three abilities as the "foundation of craftsmanship"; the ability to "localize, to question, and to open up. The first involves making a matter concrete, the second reflecting on its qualities, the third expanding its sense" (Sennett, 2009:277). Therefore, craft can be seen as more than just the act of making, but also as the understanding and reflective nature of strong craft practice. Animation is perhaps most reflective of what Sennett refers to as the "skills society", in which modern people "deploy a portfolio of skills rather than nurture a single ability in the course of their working histories", countering the idea that we are meant to do "one thing well" (265).[13] Even becoming a specialist in armature building, for example, involves numerous skills and working within multiple departments. The time needed to nurture the development of such skills is often hampered by various fiscal and situational dilemmas. Sennett states that "to work well people need freedom from means-ends relationships" (288), and that when afforded by time "slow craft" can enable "reflection and imagination—which the push for quick results cannot" (295). This is epitomised within the very inception of 3D printing in animation. Regarding pioneering the use of 3D printing in animation Brian McLean, head of Rapid Prototyping at LAIKA, refers to the trust and time given to him and fellow research Martin Maurier in developing the system:

[12] Either for single-use (such as a props), duplicates (such as replacement face or silicone hands) or hard-wearing bespoke items to be used repeatedly through a production (such as internal armatures for puppets).
[13] As seen with animator Justin Rasch—discussed in chapter 5—who has worked as a 2D drawn, CGI and stop-motion animator to extremely high levels of professionality, despite their seemingly expansive skill sets.

> The key to the success of this crazy endeavour was trust. […] it took more than nine months before we had really anything that was even presentable. The executive leadership at LAIKA from CEO Travis Knight, to Director Henry Selick and producer Mary Sandell, trusted us that we would solve all of these problems and come up with something great. […] [We] had the freedom and time to figure it all out. […] tinkering and failing time and time again.[…] if there had been a different leadership team that was more focused on immediate results, not the long game, we would have crumbled under the weight; we would not have been successful. But they really had a hands-off leadership approach. And that allowed us to fail and discover […] over and over again.[14]

These freedoms are often lacking in more industrial animation processes, weighed heavily against financial costing. With more skills and new tools come further flexibility and thus freedom, which can open whole new avenues to explore.

3.2 Digital Craft and the Invisible Hand

The concept of skill plays a central role in both craft theories and practices (Sennett, 2008; Adamson, 2007; Hoskins, 2018; McCullough, 1998; Shillito, 2013). As Glenn Adamson states, "skill is the most complete embodiment of craft as an active, relational concept rather than a fixed category" (Adamson, 2007:4). This point is seconded by Sennett, who champions the need for repetitive, hands-on learning in order to gain sufficient skills in the mastery of a craft, highlighting how computers may "remove" humans from the "repetitive, instructive, hands-on learning" that develops the mastery of their given craft (2009:39). This idea of computers or digital processes reducing our intuitive skill development is explored further by Malcolm McCullough (1998) who characterises skill as "the learned ability to do a useful process well" differentiating it from the more elusive phenomena of "talent" as requiring "learning by doing rather than inherent ability" (McCullough, 1998:3). McCullough describes how the hand of the skilled computer graphic artist performs "sophisticated" actions that are "quick, small, and repetitive, as in much traditional handwork" but is "faster" than their analogue counterpart, reliant not on "pressure" but "on position, velocity, or acceleration", as the eye no longer focuses on the "hand" but the "screen" (19–20).

[14] Interview with Brian McLean, personal communication, 6th April 2020.

This abstraction of craft through computer technology can have real-world complications when we move away from the digital and return to the physical world. As Sennett explains, "When the head and hand are separated, the result is mental impairment", which becomes more acute when using CAD (2009:52). Objects that work well onscreen may encounter problems when brought into the real world through tools like 3D printing; tolerances, scales, textures, and colours can be drastically different and must be adjusted.[15] Hoskins (2018) refers to this as "mediated disconnect" or a "twice removed" physicality between maker and object: first through the use of the software via a screen and then through the semi-automated function of the printing technology, which he notes as a key issue in understanding the "knowledge" and "craft skill" that is needed to work with 3D printing (58–59). As Adamson astutely observes, "craft skill never comes for free; it must be learned. The skilled practitioner takes proficiency for granted. It is only during the difficult process of acquiring —practised skill that the skill as such emerges" (2007:74–5). He continues, asserting that learning is achieved by "inductive experience of doing" and not simply by theory (85).

Early excitement around 3D printing was demonstrated through multiple books, symposiums, media outlets, and research centres, keen to innovate and predict its next evolution, which represented a science-fiction dream (Lipson & Kurman, 2013:1–7)[16]. Lipson and Kurman defined ten principles of 3D printing, as seen in Table 4 (2013:20–4). These were assertions based both on the realities of the time and on positivist hopes for the future that, on the surface, seem to have come true, although the complex skill required to operate these machines is undervalued. I would also contest the idea of "precise physical replication" as, even on a minute scale, replicating digital files in the physical world will always be at odds with gravity and human error.

[15] McCullough also acknowledges that CAD/CAM has the potential to "further detach people from work" through "division of labour, application of machine power, substitution and deskilling of handwork" (McCullough, 1998:188–9). He does however acknowledge that "no other equally prevalent application of computers is so closely related to that traditional locus of artisanry: the making of three-dimensional things" (McCullough, 1998:189).

[16] In the second edition of his book *3D Printing for Artists, Designers and Makers*, published in 2018, Stephen Hoskins refers to the Gartner Hype Cycle as an infographic tool, that provides insight for researchers and businesses into the growing interest in new technologies, by identifying the rise and falls of expectation, disillusionment, and the plateau of productivity (Hoskins, 2018:157–9).

1	"Manufacturing complexity is free" *3D printed objects whether complex or simple costs the same.*
2	"Variety is free" *3D printers can offer multiple different shapes or objects.*
3	"No assembly required" *The freeform fabrication style of some 3D printers allows for interlocking designs.*
4	"Zero lead time" *Print-on-demand production model.*
5	"Unlimited design space" *Complex designs are no longer beholden to any one tool or skill set.*
6	"Zero skill manufacturing" *Ease of use requires less operation "skill" compared to more traditional methods.*
7	"Compact, portable manufacturing" *Can print beyond its own size, determined by its printer bed or with adjustment larger than itself.*
8	"Less waste by-product" *By printing only what we need there is less leftover material*.
9	"Infinite shades of materials" *3D printing allows for new blends of raw material to be combined in ways previously impossible.*
10	"Precise physical replication" *3D files can be endlessly copied and reproduced, scanning can also allow real-world objects to be replicated perfectly or manipulated creatively.*

[*Table 4*. Lipson & Kurman's (2013)Ten Principles of 3D Printing]

As McCullough points out, "predictions […] of new technologies have known fallacies" that they may "replace" earlier processes, that they will "change the work", and that only the work shown "on our instruments […] [are] appropriate" (McCullough, 1998:77–8). Similar fears were felt in the early days of 3D printing's adoption into stop-motion fabrication. As Andy Gent, owner of Arch Model Studio acknowledges:

> When they first started to appear, people did go "Well, there's my job over" […] [but now] they're excited. […] If you're [a] really good […] model maker, you'll just see it as a useful

> way of making a better end result. Whether you're the operator of the machine or not. Most things that are built require multi […] department collaborations […] [and] if somebody invents a new tool, and it does an amazing job, you certainly want to be able to [use it].[17]

The potential and natural attributes of 3D printing have settled into a more mature and considered space. However, there remains the possibility for exploration through pragmatic—and, importantly, physical—interaction with the materials and technologies, rather than simply hypothesising about their use.

3.3 Printing Tools and Moving Parts

A wider use of the technology both inside and outside of the puppet has developed, as Lucy Johnson emphasises “visionary creatives […] are taking the tools of big industry and with exceptional skill and dedication, re-employing them as the tools of bespoke artisanship” (Johnson, 2015:9). As Sennett describes it, 3D printers could be considered an “all-purpose tool”, due to their “sheer variety” and potential to “expand our skills if only our imagination rises to the occasion” (2009:195). However, as McCullough notes, “new tools” and “new thinking” rarely stimulate a new way of working; instead, a “new task is done for quite some time by means of adapting existing tools. Thus, invention and innovation are most often gradual” (1998:75). Most 3D printing within stop-motion production has been used to produce artefacts that were already able to be made, albeit to lower yield or through more process-heavy means. As Sennett suggests, perhaps the most challenging aspect of a new tool or skill for the “maker” is the concept of the “domain shift” in applying a “tool initially used for one purpose […] to another task” (Sennett, 127). A need to go back and forth between printed parts and traditional hand tools highlights a continued need for both digital and analogue skillsets. This along with a need to develop the final look of the 3D printed pieces, is highlighted by Gent:

> 3D Printing [is] still not as good as […] being done by hand. If you make anything by hand, it'll be way better quality. […] It's very close, and if you've got the time, you can print out an almost perfect surface. Where it becomes really useful is […] [through skipping] other processes. So, although you could sculpt something amazing, then you'd have to mould it and […] cast it out and then you'd have to clean it all up. […] [By] 3D

[17] Interview with Andy Gent, personal communication, 1st January 2020.

> sculpting, […] you bypass the moulds and go straight to print. So, you've saved a lot of time, therefore, you've saved a lot of money. So, it's very cheap and viable.[18]

Gent is wary of placing too much reliance on machines that, like any other, can break or malfunction at any point between initial design and the final object. This can have a drastic effect, especially in the time-sensitive world of commercial animation production:

> Being reliant on something […] if it goes wrong overnight, you've no comeback. […] Doing it by hand, you're watching every process going through and […] [there's] very little […] room for it to go wrong. But we've had 3D printers that have pushed the liquids inside themselves and then glued the entire working parts up. […] They're very reliable more often than not, but you still need to be mindful that it might not work out. Generally, that's where you have several machines, so you've always got something else running in your unit to try and offset [it].[19]

Although Gent is an advocate of 3D printing, using it throughout his London-based studio, that creates some of today's highest quality stop-motion work, he remains pragmatic and acknowledges that 3D printing, although powerful, is not the only way of working—and that often poor decisions are made based on the push of modernist ideals and naivety:

> People blindly [think] […] it is the be-all and end-all and […] it absolutely isn't. It's a good tool to have in. But there are many good ways of doing things and I think you have to be mindful, you just have to know all the options, and then use them wisely. […] I've seen people blindly print things out that were massive. They've cost an absolute fortune on other jobs with other production companies and there is no need to do it that way. But they just want to do it because they all think […] 3D printing does everything.[20]

Screen Novelties, a studio based in Nevada, USA, have a bold, graphic design—reminiscent of the work of George Pal and Rankin/Bass, and ideal for 3D printing. As a relatively small studio predominantly known for their work on television specials and advertisements, the need for nimble production scaling is another useful consideration of 3D printing. In conversation with co-owner/director Chris Finnegan, the ways in which the studio uses 3D printing were outlined:

> The main benefit as we see it is the ability to do replacement mouths and replacement heads more easily. In the old days, we would have to hand sculpt […] every single replacement mouth and […] getting the registration to be spot on is tricky you have to do

[18] Interview with Andy Gent, personal communication, 1st January 2020.
[19] Interview with Andy Gent, personal communication, 1st January 2020.
[20] Interview with Andy Gent, personal communication, 1st January 2020.

> a lot of testing with the sculpture and adjustments and one of the benefits of 3D printing is once you have your main head you can easily add variations in mouths, you can imbed registration point[s] and […] if there's a magnet interface between the head and the face you can model that in at the beginning so everything just comes back very precise. That said there is still quite a bit of work once we get the prints. We haven't used full-colour prints […] [we still] sand, […] texture, […] and paint them to blend it into the look of our puppets, we'll even mould and cast them sometimes if we have multiple puppets so it's a shortcut but it's still a lot of work to get from A to C. […] [Although we use] them more for the head[s], we have done bodies, […] arms and hands, […] [even] the whole sculpture and mould and cast those out of silicone. […] We have done it for the cores in puppets where there's a very specific kind of armature placement that we need, and it can be very helpful.[21]

In the next section we can see how various practitioners have used 3D printing as both a tool and a way of creating tools for unique applications and to enhance the puppet fabrication process.

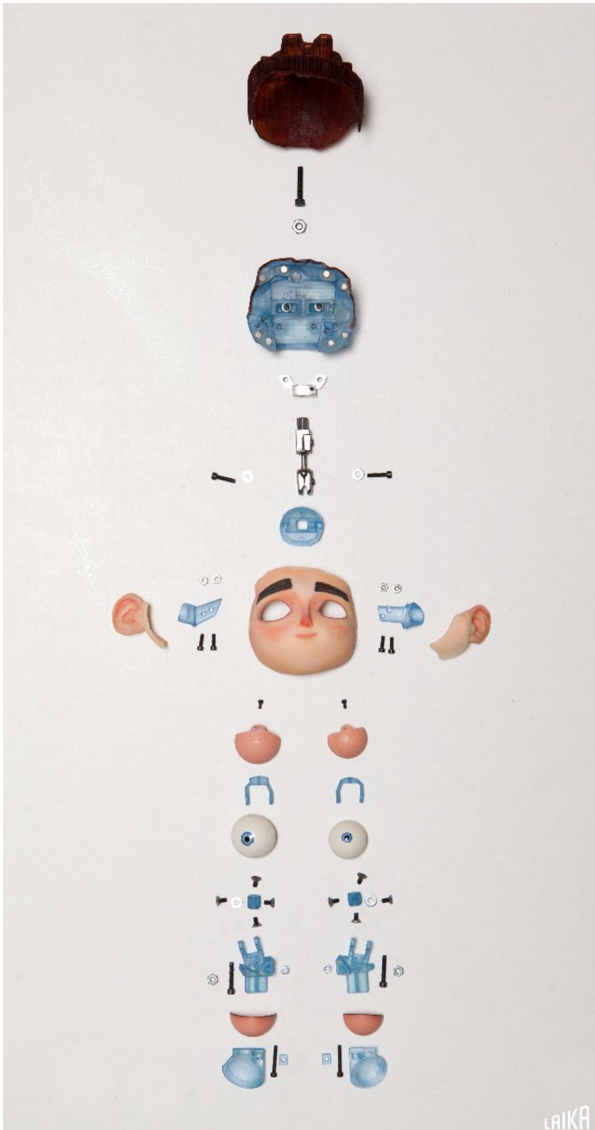
3.3.1 Armatures, Rigs, Cores and Moulds

Although 3D printing is most often used for replacement animation,[22] LAIKA innovated a system of inner head mechanics, in tandem with their pioneering faceplates (Figures 16.1-2), allowing for both face registration and eye rigging:

> Each eyeball was an engineering feat. There is a water-soluble support material that is sprayed down alongside the resin, a material that washes off leaving you with a mechanically impossible piece that is locked together and movable. That material is one thing that makes Objet printing so impressive. You are not limited to printing solid objects, you can print completely assembled […] working ball and socket joint. (Dunlop, 2009)

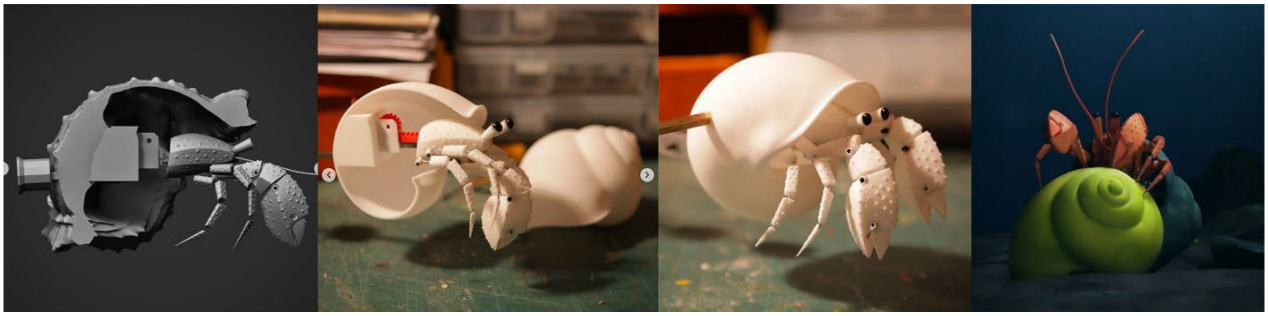
The development of the eye system highlights the unique benefits of mixed-material printing and the ability to engineer parts that can be printed pre-assembled. This system has been replicated most clearly in Bharoto Yekti's paper that used "knock-down strategies" for "home-scale" 3D printers (Yekti, 2017b), demonstrating that, although similar systems are possible, access to more unusual materials and larger-scale machines presents an issue for smaller-scale productions.

[21] Interview with Chris Finnegan, personal communication, 26th March 2018.
[22] See chapter 2.



[*Figure 16.1.* Inner head mechanics from *ParaNorman* (2012). *Figure 16.2.* Inner head mechanics from *The Boxtrolls* (2014). Images used with Special Thanks to LAIKA Studios]

Dadomani, an animation studio based in Milan, created *Skills*, a short animation series highlighting the aquatic skills of underwater creatures, many of whose exoskeletons were created using 3D printing, with winder rigs incorporated directly into the internal cavity of some puppets, as seen in the episode highlighting the symbiotic relationship between hermit crabs and sea anemones (Dadomani, 2021). 3D printing was selected due to the bold, graphic design of the creatures and to allow for greater control over the movements. For many of the puppets, traditionally cut or CNC-milled armatures were used due to their overall resilience and sensitivity to movement.[23]

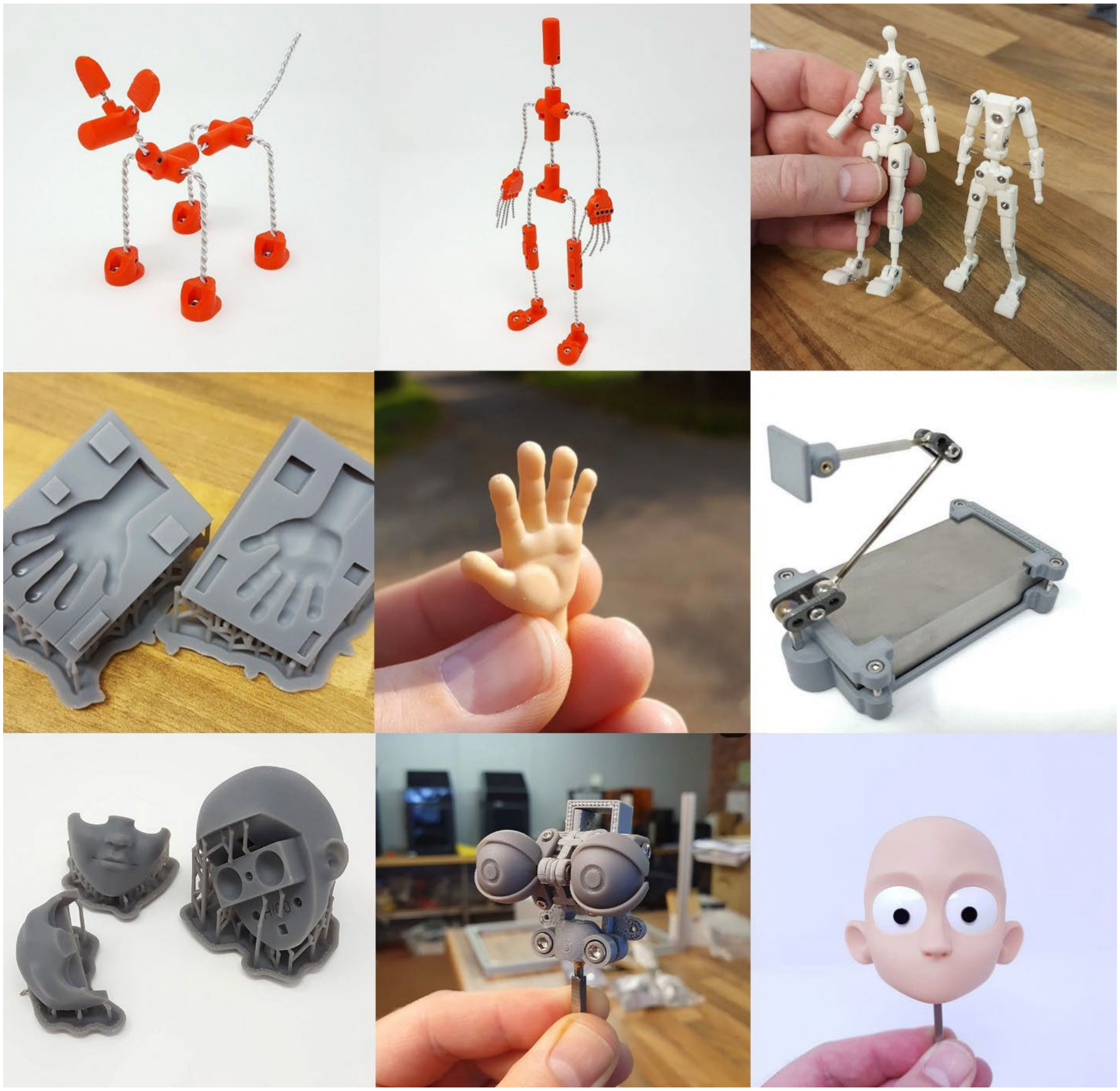


[*Figure 17.* Internal mechanism and exoskeleton 3D printed in nylon. Wire and screws incorporated into the design. Image used with thanks to Dadomani]

Armatures are highly crafted, intricate mechanisms required to pose puppets; they need to be accurately tensioned to hold poses for long periods of time. They can be manufactured using cheap, twisted wire or use highly sophisticated, articulated ball and socket joints—created by cutting, milling, and soldering various metals—which can prove costly. Large studios often hire in-house armaturists to create the fleets of armatures needed for feature or series production. As they inevitably wear through use, they often require maintenance, fixes, or sometimes multiple copies of the same puppet to last throughout production (Walsh, 2019:27–8). So far, widespread use of 3D printed armatures has not been achieved, likely due to the inadequate strength of most 3D printing materials. However, some fabrication companies that sell kits, pre-made, and bespoke armatures have begun using 3D printing to create internal components for stop-motion puppet construction, as well as other 3D printed products for animation production.

Animation Toolkit in Manchester, UK is a specialist animation armature company that offers a range of products and materials for stop-motion production. They have used 3D printing to create base character heads, hand moulds and snap-fit bodies, which enables quick, light, and simple fleshing out of a puppet's torso and limbs (Animation Toolkit, 2020). Stop Motion Shop by Julian Clarke also offers different-sized hands made using 3D printed moulds. He has developed an articulated head rig containing eye sockets, as well incorporating 3D printed joints for added durability in the often-fallible style of wire armature (stopmotionshop.com, 2020).

[23] Personal correspondence with Dadomani, 30th April 2021.



[*Figure 18.* Range of 3D printed parts created by Julian Clarke of stopmotionshop.com. Image used with thanks to Julian Clarke]

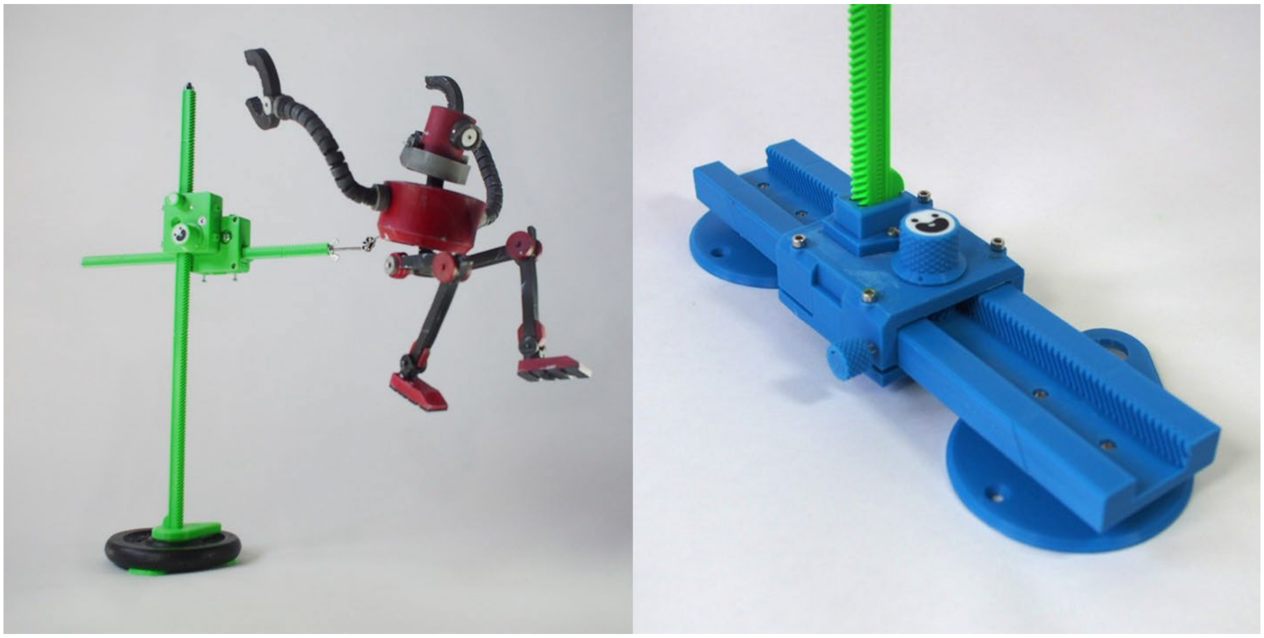
ModiBot is a low-cost articulated figure developed by toy designer Wayne Losey. This simple, small-scale armature can be purchased through various vendors but is also offered on the ModiBot website alongside pre-cast model kits and free downloadable print files. This product was designed to give users a basic articulated character to adapt, either through additional 3D printed parts or other crafting materials (modibot.com, 2022). The easy snap-fit joints, sustainable print-on-demand business model and low purchase price makes the product ideal as both a poseable toy and learning aid for 3D printing, stop-motion, and CAD modelling.[24]

Paul Siegel's of Armature Nine (armaturenine.com, 2022) creates 3D printed armature and artist mannequins, developed in 2012 using a mixture of snap-together tension joints and plates screwed together post-print, and available in a variety of scales and characters [Figure 19] with custom designs and additional components to adapt the structure yourself. This product showcases the creative potential of 3D printed armatures. Although durability, stability and tensions remain a potential issue, the system is adequate for training or shorter/low budget productions (Armature Nine, 2015).

[*Figure 19.* Range of 3D printed articulated characters created by Paul Siegel of Armature Nine. Images credit armaturenine.com with thanks to Paul Siege]

Friendly Beans Studio's Luke Bosshard developed a range of 3D printed winder rigs that are made with green screen coloured filament, including a motorised version for use with motion control; an excellent example of the stability and open-access potential of 3D printing for creating your own tools.

[24] Stickybones is another poseable figure for drawing and animation; it contains rare-earth magnets allowing it to be posed and stand aloft on a steel plate provided with the figure. 3D printing was used to prototype and create the initial mould; however, the final product is not 3D printed (Autodesk Fusion 360, 2016). Although offering a good range of movements, its easy snap fit assembly can cause the joints to pop out of place if extended too far. This and a lack of bespoke tensioning stop it from being used for larger commercial projects (Stickybones, 2018: 01:38).



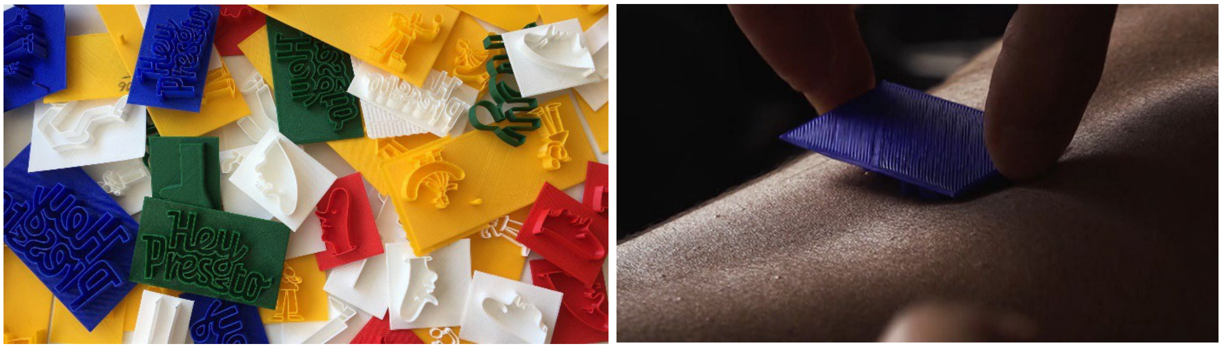
[*Figure 20.* Winder rig available at MyMiniFactory.com. Image used with thanks to Luke Bosshard]

3D printed moulds can be used for complicated shapes or to cast in materials not currently available through the printing process itself. 3D printing can also be used to create basic shapes that are hollow, light, bespoke and customisable, for example, the head cores in *My Life as a Courgette* (2016) were 3D printed due to their oversized scale, in what was for the most part a very handmade looking film (Grober, 2016; INITIAL.fr, 2017).

3.3.2 Stamps

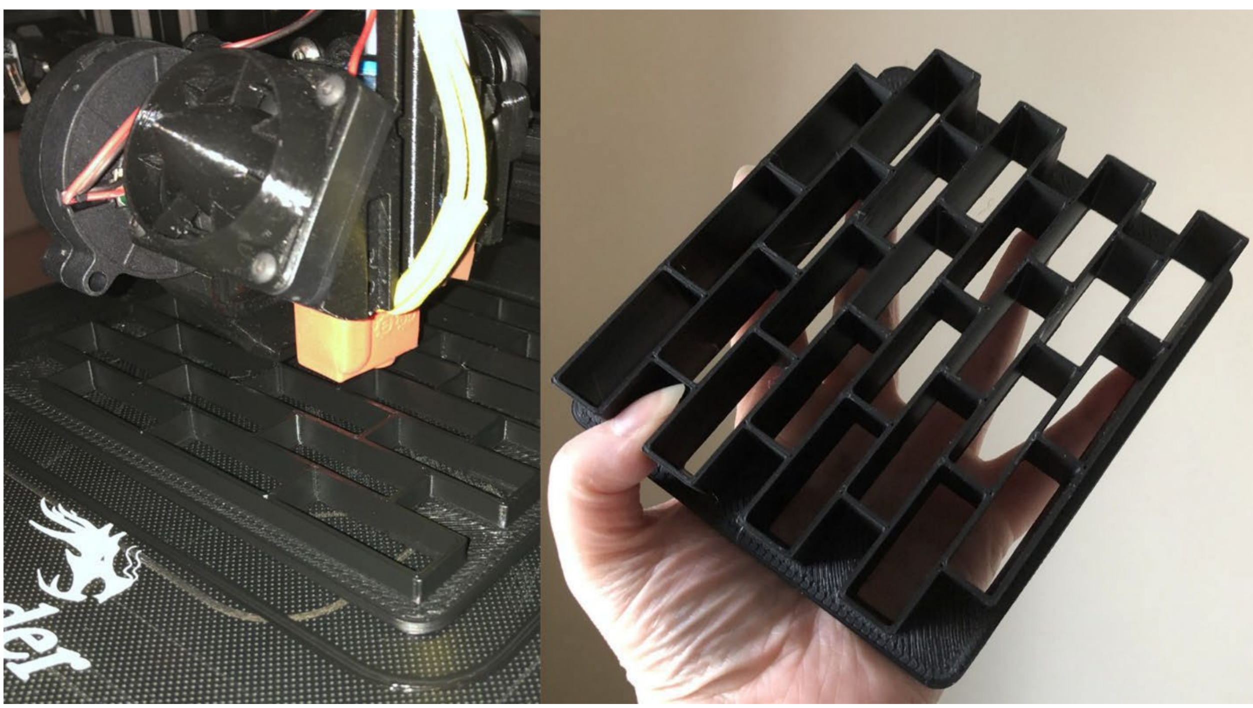
Hey Pressto (2017), created by Animade studio for the DBLG agency,[25] used 3D printed stamps [Figures 21.1-2] pressed onto human skin to create animated sequences and loops (DBLG, 2017). Created purely for experimentation purposes, the film showcases the use of 3D printed tooling in a novel way, using a living canvas to create a unique form of narrative image-making.

[25] Who previously commissioned *Bear on Stairs* in 2014 (see section 2.2.1).



[*Figures 21.1-2.* Stamps for *Hey Pressto* (2017). Copyright DBLG]

Another 3D printed stamp tool was used in *Brunch* (2021) by Marnik Loysen. As the film takes place primarily in a café, with industrial brickwork walls, I was contacted to create a brick pattern stamp to aid in the construction of the set, produced to the requisite scale measurements of the artist. The stamp, used to imprint a brick pattern into clay before being dried and painted (Figure 22), was created in CAD and printed at a low speed using a high-density infill to reduce potential warping or breakages through use.



[*Figure 22.* 3D printed stamp made for wall details on *Brunch* (2021). Image used with thanks to Marnik Loysen]

The ability to react quickly and creatively to issues that arise during production is part of the filmmaking process; creating simple tools like this can solve bespoke design issues as they present themselves, rather than relying on prefabricated objects that may not be suitable. It could also allow for a digital library of tools, props and set components to be created and shared for future projects.

3.3.3 Other Novel Uses of 3D Printing in Stop-Motion

Zoetropes, early motion devices from the nineteenth century, often consist of a cylindrical wheel housing a series of images viewed through slits in the side of the cylinder that, when rotated, reveals the illusion of moving images (Furness, 2017:17). Mat Collishaw's 3D printed zoetrope *All Things Fall* (2015), is a large, fully functioning zoetrope with looping, 3D printed characters depicting acts of cruelty; this fine art approach to using both zoetropes and 3D printing demonstrates how modern technology, ancient techniques and social themes can be combined with expressive design (Jones, 2015). The zoetrope allows for audience participation and live animation, using the highly detailed rendering offered through 3D printing.[26]

[*Figure 23. All Things Fall* (2015). Copyright Mat Collishaw]

[26] Similarly, artist Akinori Goto created a 3D printing zoetrope to create a circular mesh rendering figures into a continuous shape (Tech Insider, 2016) that when positioned in a thin beam of light reveals a person walking or dancing (JARRE115, 2016).

Similar to the work of Dadomani studio,[27] LAIKA 3D printed an exoskeleton for the Moon Beast character in *Kubo and the Two Strings* (2016), creating individual, segmented shells that illuminate under UV light, attached to an internal armature (Rotoscopers, 2016:00:05).

[*Figure 24.* Moon Beast from *Kubo and the Two Strings* (2016). Image used with Special Thanks to LAIKA Studios]

3.4 Knowing the Tools

In most—if not all—of the examples above, analogue, and digital skills have been combined. Hoskins suggests "craft of the digital" as a term to acknowledge that, without adequate practical skills developed through interaction with material, it is not likely you will be able to work in a digital environment effectively (2018:73). As Ann Shillito states, "know how" comes directly from physically manipulating materials, through handling and tools, learning, exploring, and inquiring with a "what if approach" (Shillito, 2013:29). To better understand the required technical skills and creative potential of this technology from an empirical standpoint, I have completed training in various 3D technologies.

[27] Discussed in section 3.2.1.

All digital fabrication tools require an input, design, or model, from which they plot a path. A modelling software, itself a tool, is required to print 3D objects. 3D printers exist in a variety of forms using a range of technologies, which can be used in different ways. 3D printing is but a tool—as Hoskins reiterates, “the technology in itself will not make art; it is inanimate and subservient to the user” (Hoskins, 2018:12). Any tool requires understanding, comprehension and, as McCullough acknowledges, “practice”. To fully embrace a tool “you must learn how each tool works, how one tool works with another, and how all are maintained” (1998:61). From here we will now take a comprehensive look at the skills and modes of engagement needed to use 3D printers and how this can be applied to animation production.

3.4.1 3D Modelling

A range of software can be used to create 3D models, which have been developed for the engineering, architecture, product design, as well as the animation and gaming industries, and can be largely separated into either solid or surface modelling systems. Solid modelling or CAD software is perhaps best suited to 3D printing, as shapes are represented as “a collection of volumes” which “speak” more “fluently” with the printers (Lipson & Kurman, 2013:93). Surface modelling, also known as 3D computer graphic software or polygonal modelling, interprets “polygonal” shapes as a “virtual net” that correspond to a “data point on a theoretical grid” saved in the “design software” (94). Much software now incorporates elements of both “parametric” and direct modelling, so users can work within constraints or in a more freeform manner, allowing for “editing and experimenting with their design” (93). Gaining proficiency in software takes a long time; trying to review every software program would be a study in itself. In this study, Fusion 360 was selected for its simple user interface, solid modelling capabilities, and free/low-cost use policy for students and small businesses.[28]

3.4.2 Direct Coding

Direct coding, through which instructional code is manipulated before being sent directly to the machine, is an alternative to 3D modelling. This is a fascinating avenue to explore, allowing for

[28] Significant time was also given to Rhino as a prominent and powerful solid surface modelling software within engineering, including powerful plug-in’s such as Grasshopper and Silkworm that allow for direct code manipulation. However, for this study, much of the practical modelling was done in Fusion 360.

direct manipulation of a machine's pathway via coding, creating interesting textural or performative tasks. While outside of the scope of this particular study, Rhino can incorporate aspects of direct manipulations via plug-in's, within a graphic user interface.[29] The Grasshopper plug-in enables the creation of shapes or patterns via parametric nodes and data for customisable infills, variations in series of objects, using open objects and the manipulation of tool paths.[30] This can be altered further through the additional plug-in Silkworm, which translates Rhino and Grasshopper geometry into g-code that can be thoroughly altered, allowing for novel materials to be used.[31]

3.4.3 Scanning

There has been significant use in the arts (and other industries) of 3D scanners as a way of digitising physical objects into digital models. Scanning allows for surface textures to be included in the digital file, more closely replicating physical qualities and individual tool marks or fingerprints in the digital world. Digital scanning has continued to improve, although some additional modelling is often required to make models watertight for digital fabrication processes including 3D printing. Gent highlights how 3D scanning has aided multiple projects:

> By [using] 3D scanning, we [were able to] more or less press the enlarge button. Then we've got [the object] 15% bigger. To do that traditionally would have been very difficult.[32]

The ReAnimate Project, developed by Manchester Metropolitan University (in collaboration with the Ray and Diana Harryhausen Foundation, the Waterside Arts Centre, and Mackinnon and Saunders), has used scanning technology to digitally archive historic materials for preservation and study of delicate original artworks (mmu.ac.uk, 2019).

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[29] A graphic user interface remains a preferred way of working for many, due to its use of "hand-eye coordination", allowing us to "point" and recognise and responded to "graphical feedback" rather than remember "tedious typing" commands (McCullough,1998:116–9).

[30]Further information regarding the ways Grasshopper can be used can be found at www.3dwasp.com /en/3d-printing-grasshopper/

[31] Further information on the Silkworm plug-in can be found at www.grasshopper3d.com/group/silkworm

[32] Interview with Andy Gent, personal communication, 1st January 2020.

3.4.4 File Formats

The Standard Tessellation Language (STL) file format, developed in the 1980s, digitally slices design files into a printable format. As early computer memory was "limited and expensive […] the STL file format removed some design details", however this initial benefit is now a limitation (Lipson & Kurman, 2013:101). Although STL is still the most commonly used file format due to its wide compatibility with almost any printer, other file formats have emerged including the Additive Manufacturing Format (AMF), co-authored by Lipson, to maintain "the surface mesh structure of the STL format" (102) whilst storing all data and metadata of the model, including colour and material choices, with a very low error rate. Surpassing AMF somewhat is the OBJ format developed by Wavefront Technologies, which is both accurate and allows for the transfer of colour, material, and texture detail in conjunction with its corresponding MTL (material template) file. Developed collectively by Autodesk, 3D Systems, Stratasys, HP, and Microsoft, 3MF is similar but more widely used than AMF due to its association with bigger industries. It is highly compatible and accurate, stores all data related to the model in a single file and is generally considered "ready to print", though there are concerns that it could become a "proprietary" format, excluding low-budget software or hardware alternatives due to its origins (Xometry Europe, 2020).

3.4.5 Slicer and Driver Software

Slicing software interprets and converts 3D models to printer-ready g-code. Some printers come with their own dedicated slicer, and there are also open-source programs, such as Ultimaker Cura, that speak to multiple 3D printer brands. Within these programs you can alter various elements of the printing process—including internal infill structures, supports, layer heights, temperatures, speed, and velocity—and check an object's printability, highlighting overhangs or sharp angles that may benefit from further supports. Different printers require their own slicers as they create objects in different ways. Additional programs can offer further control and information to aid printability or allow multi-material 3D printing.

Multi-material printing allows combinations of material qualities and full-colour printing. As Lipson and Kurman highlight, multi-material printing offers exciting opportunities to "co-print multiple materials simultaneously, patterning them together into complex, new meta-materials" (2013:266). This can be done manually in some machines, by halting a print and replacing materials, although maintaining accuracy can be difficult. More commonly, a dual extrusion or driver software is used to combine materials. The use of multi-colour printing in stop-motion is perhaps the most interesting and widespread application of this process in the animation industry, particularly the use of the Cuttlefish® driver for voxel[33] printing by LAIKA.[34]

3.4.6 3D Printers

3D printers construct objects using a wide spectrum of technology which is developed and expanded upon each year. Table 5 highlights the current 3D printing technologies being used in the animation and broader fabrication industries and will be referred to throughout the thesis.

Fused Deposition Modelling (FDM) uses a coil of plastic filament extruded through a heated nozzle. The 3D object is formed by coiling the material on a flat base. As one of the earliest forms of 3D printer, there are many iterations, re-designs, and DIY versions of the machine available. Its open-source process, range of materials, simplicity, and multi-material printing capabilities make it particularly well suited to experimentation (Shillito, 2013:123). Generally, the quality of the finished pieces and reliance on supports make it less desirable for highly detailed work.
Stereolithography (SLA) uses light-reactive materials, known as resins, that are cured layer by layer using UV light (Formlabs.com, 2021). A platform moves down into a resin bath; as the platform reverses, the UV light cures the layer before it is dipped again, and thus a 3D object is built up in extremely thin layers. It too relies on thin supports. Once printed, the objects can be left to cure in the sun, or for a better result, washed in a bath of isopropyl alcohol (IPA) and cured in a light chamber. A range of SLA resins are available, many of which are explored in chapter 4.

[33] Voxels are three dimensional pixels.
[34] More detail about this can be found in section 7.3.1.

Digital Light Processing (DLP), developed by EnvisonTEC, is similar to SLA but instead presents a silhouette of each layer onto photo-polymeric material, allowing for fast, accurate object creation with an extremely fine detail finish. Its “flesh-coloured material” incentivised Aardman to use this technology for their 2012 film *Pirates! In an Adventure with Scientists!* (Hoskins, 2018:50–1). A few low-cost desktop machines using this technology are now available.
Powder Binder 3D Printing—manufactured by 3D Systems, which bought out Z Corp in 2011—uses a plaster-based composite powder material that sits within a bin; layers of the material are dropped layer by layer, and an ink-jetted binding material is added to solidify it before more material is added. Once complete, the object is excavated from the bed, with un-treated material acting as a support, and when the object is removed the remaining powder is reused for the next print. It is also possible to print in colour using the system (Hoskins, 2018:47–50).
Laser Sintering (SLS) uses a laser to fuse particles together. A bed of the powder moves and is precisely sintered layer by layer with a new layer of raw material being dragged across between each layer. The surrounding un-fused material acts as a support. This can be used with a range of materials including metal, nylon, ceramics, and glass (3DINSIDER.com, 2020).
Laser Melting (SLM) works similarly to SLS in that it also uses a laser to combine fine layers of powdered material. However, SLM fully melts, rather than sinters the compounds together, which creates stronger parts (3DINSIDER.com, 2020).
Direct Metal Laser Sintering (DMLS) is an additive manufacturing process that creates 3D printed metal objects by sintering the material and offers an impressive range of metal alloys and materials.
PolyJet technology—originally manufactured by Objet and now owned by Stratasys—uses a print head that sprays liquid photopolymer into extremely thin layers onto a bed and solidifies it with UV light. It is highly detailed and offers a range of solid and flexible materials, as well as a range of colours including clear. The uncured water-soluble material is used as a support during the build and can be washed away post-print (Hoskins, 2018:52; Lipson & Kurman, 2013:70).

Multi Jet Fusion (MJF) technology, created by HP in 2016, involves laying down a layer of powder, after which an inkjet head spreads a fusing and detailing agent over the surface. An infra-red heating unit passes over the surface and any areas with the agents will fuse to the previous layer. As the previous layers remain molten while the next layer is being added, this allows for each layer to fuse together completely, increasing the durability and the strength of the overall print (Kauppila, 2021). The uncured powder is recycled at the end of the printing process. This process allows for complex colour matrixes to be created.

[*Table 5*. 3D Printer Lexicon]

3.4.7 Combination Tools

Combination tools, such as the Diabase H-Series, combine a multi-material 3D printer and CNC milling into a single 5-axis machine for uninterpreted fabrication (diabasemachines.com, 2021). Other machines incorporate 3D printing, CNC milling, laser engraving and cutting (Mensley, 2021). Such tools are taking industrial 3D printing beyond prototyping and into full fabrication.

3.5 Bureaus

Using a 3D printing bureau or other digital fabrication company offers a convenient way to explore a wider range of materials and/or machines, whilst saving on costs associated with updating machinery and bulk-buying expensive materials. Allowing access to top-of-the-line machines and materials without a prohibitive initial outlay. Certain materials and forms of printing remain expensive, so it is best to experiment with cheaper materials and technologies before committing to their more expensive counterparts, but it is imperative to consider the material and technological changes to the surface finish and scale. It is also important to maximise the use of printer beds and machine volumes, as pricing is often based on the initial setup of the print as well as the amount of material and energy used. Bureaus are invaluable to creative practitioners wishing to explore 3D printing in their work. However, the skill and understanding required to reach this point should not be underestimated. Bureaus were used extensively in both the long-form pilot study documented in chapter 4 and the first case study documented in chapter 6 within this thesis.

3.6 Knowing the Materials

As Hoskins, Sennett, Adamson and McCullough have all determined, without sufficient understanding of both the tools and materials involved in any one skill, whether analogue or digital, the potential of a new process cannot be fully understood. As McCullough suggests:

> [W]here the tool is an effector or a probe, a medium is a substance that may be sensed or altered [by tools and] […] the best way to begin understanding any medium is as a range of possibilities […] often articulated in terms of structure. Wood has grain, paper has tooth, metal has temper. Understanding of structure is implicit; it is learned through experience. (McCullough, 1998:194–6)

These considerations are explored in the next chapter, which documents a long-form pilot study conducted to gain practical knowledge of equipment, technology, machinery, and materials to build a repertoire of tacit knowledge to aid in the development of further case studies.

Chapter 4. Long-form Pilot Study: Material and Joint Design

4.1 Project Outline

To determine how 3D printing could further aid the puppet-making process, an initial pilot study was conducted to develop the design of a simple, interlocking snap-fit joint. This joint was subsequently used to conduct research into a wide range of 3D technologies to gain material knowledge, as well as analyse and evaluate them for future stop-motion applications. At this stage, the study was developed into a broader long-form material and design study to create a range of samples using various 3D printing technologies. Multiple materials were worked with at various scales and with alternative post-printing processes to establish a sample library, both for the researcher to learn the requisite skills to use these technologies and also to assess how these materials and technologies could be used in the following case studies and in the future.

4.2 Initial Study Summary

Reflecting the current uses of 3D printing in stop-motion, as outlined in chapters 2 and 3, which often parallel early historical techniques, and recent developments in novel flexible materials, the initial pilot study was developed with the aim of creating a flexible joint system for use within the puppet itself, to reduce the need for multiple printed figures and give authorship back to the stop-motion animator working on set. Key words were used to identify literature in different disciplines, including engineering, soft robotics, prosthetics, and surgical implements, against a list of parameters unique to stop-motion productions (seen in Table 6) that were used to analyse the papers. Also important was remaining open to novel materials, concepts, and practices that, although not perfectly suited to the needs of the study, could offer a wider understanding of 3D printing possibilities for manufacturing, joint creation, or other fabrication techniques.

Within stop-motion a friction-based joint must hold a pose over multiple frames, therefore this was necessary in the initial joint design. To create a flexible limb, akin to a “rubber hose”[35] character, a curved configuration using multiple joints in a cabled system was required. The system needed to be repeatable in various scales and remain unobtrusive to the animator by not adding any further complexity to their workload. At a minimum, any device proposed should be as functional as any existing forms of armature construction and, if possible, offer some

[35] Discussed in chapter 2 section 2.1.

additional advantage or benefit to the overall look or process of animation. None of the papers offered a viable joint-system for use in a stop-motion armature.[36]

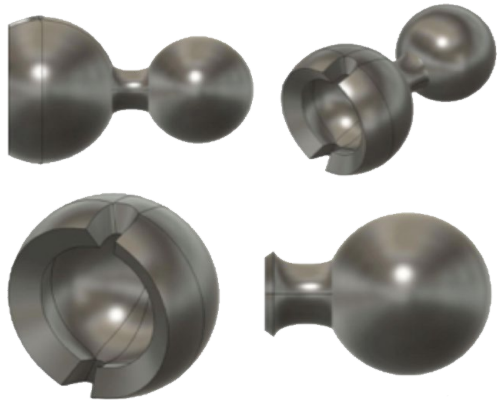
	A	B	C	D	E
Can the proposed arm or joint be used for the creation of a curved formational limb?	Y	Y	Y	Y	Y
Does the joint or arm hold its shape and remain rigid?	-	Y	Y	Y	Y
Is it able to be posed?	Y	Y	Y	Y	Y
Would any subsequent friction device or implement get in the way of the animator/add to the animator's workload?	N	Y	Y	Y	Y
Is the joint scalable?	Y	-	-	-	-

[*Table 6.* Papers and their suitability against the discussed parameters. Y = Yes, N = No, - = possibly/ unexplored in paper. A = "3D-printing of a non-assembly, articulated models" (Cali et al., 2012); B = "3D printing of variable stiffness hyper-redundant robotic arm" (Yang et al., 2016); C = "A novel layer jamming mechanism with tunable stiffness capability for minimally invasive surgery" (Kim et al., 2013); D = "Apparatus for temporarily engaging body tissue" (Goodman, 2003); E = "Vacuum packed particles as flexible endoscope guides with controllable rigidity" (Loeve et al., 2010)]

4.2.1 Initial Joint Design

Drawing upon the papers reviewed in the previous section, the most interesting results came from the papers of Yang et al. (2016) and Cali et al. (2012). The use of the ball and socket joint design and soft/pliable multi-material printing, as a way of creating friction, influenced my own initial design. A similar system has been employed for low-cost puppet creation, by using doll armature found online or in craft stores (Priebe, 2011:77–83). The design is made of a cup and a ball attached by a neck.

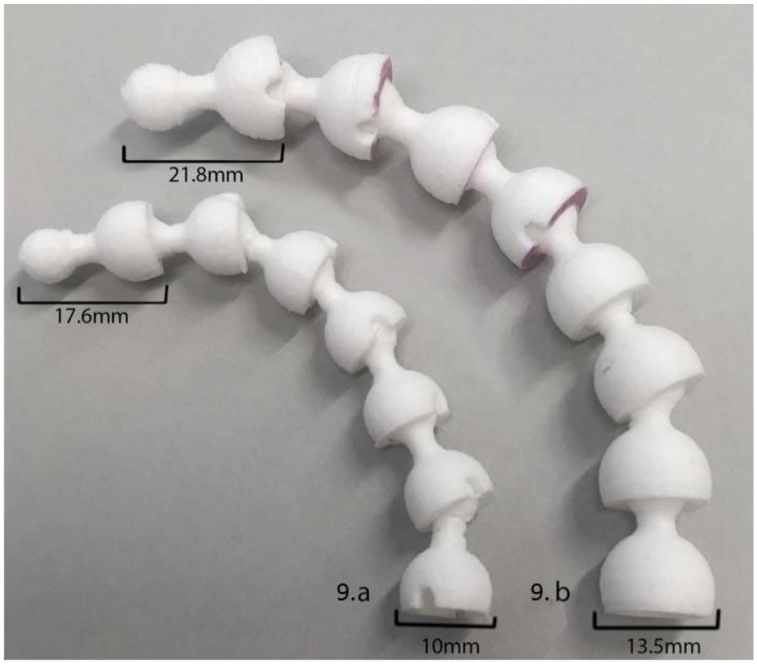
[36] A more detailed analysis of each paper can be found in Appendix A.2.



[*Figure 25.* Altered design]

In order to use flexible materials such as PolyFlex™ (Thermoplastic Polyurethane Elastomer) with FDM printing, the design was slightly revised; the neck was lengthened and thickened, and the ball diameter and wall thickness of the cup was also increased to create a tighter fit, give a greater angle of movement, and increase printability [Figure 25].[37] The results were positive in both a 10mm and 13.5mm diameter design [Figure 26]. The modular design snapped together with ease and the rubberised material added friction between the ball and socket which helped hold its position when posed. The slits on either side of the cup design were later removed as they reduced the overall hold and were unnecessary when combined with the flexible material. The slitted design was retained for later use with rigid filament printing, such as PolyPlus™ PLA,[38] to see if it would aid assembly and movement.

[37] When using flexible filament for FDM printing, thin walls are less stable during printing which can lead to distortions or printing failures.
[38] PLA (polylactic acid) a biodegradable type of plastic that is manufactured out of plant-based resources such as corn starch or sugar cane (Ramon, 2013).



[*Figure 26.* 10mm and 13.5mm articulated modular joints]

The process was followed by incorporating a rigid PLA filament into the same FDM printer. Once printed they did not snap together due to the angle of the cup. However, there was some success in mixing the two samples by putting a soft ball into a hard cup. A good amount of friction was created but through repeated use the neck became fractured and broke. It was believed this could potentially be resolved by reviewing the design and making the neck and cup in hard material and creating the ball in rubber. When a hard ball was put into a soft cup, the friction between cup and ball was less strong and it regularly pulled apart. The cup angle was increased in a subsequent test to allow for the hard material version of the joint to fit together. They did snap together, however the connectivity was greatly reduced and, when pushed too far into a curved position, simply fell apart.

Further research using solid materials was conducted using SLA printing due to its ability to create small, highly detailed objects. The initial design was printed in photopolymer resin[39] using a Formlabs SLA printer in different scales to see how fine and small the joints could become. Due to the differing accuracies between SLA and FDM technology and the cup angle, the joints were unable to snap together. It was possible to reduce the scale to 5mm by 7.4mm [Figure 27].

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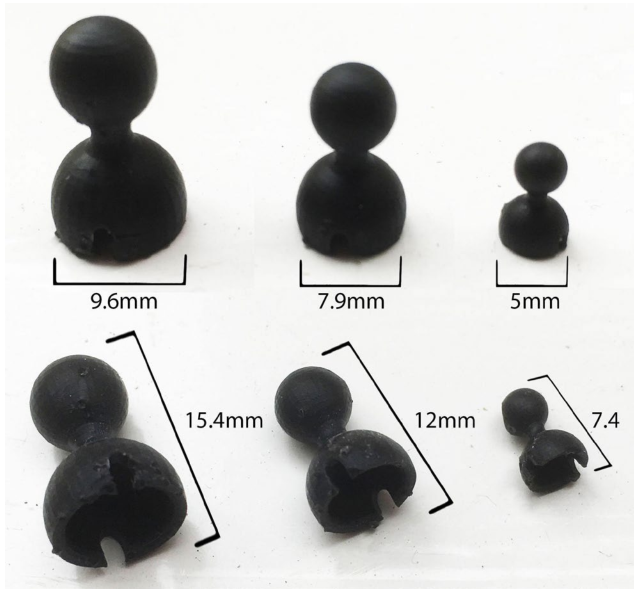
[39] Photopolymer resin is a substance whose properties change when exposed to light (Hoskins, 2013).

This design needed to be altered to increase the curve of the cup and shorten the neck to allow for secure fit.



[*Figure 27.* Photopolymer resin joints printed in an SLA printer]

4.2.2 Conclusion of the Pilot Study and Next Steps

Referring to the parameters that informed the reading, the joint system developed during the initial pilot did configure into a curved shape, allowed for posing, created a semi-rigid position and required no further material state change or addition devices to create friction or rigidity. Due to the use of rubbery printing filament the modular design was easily assembled [Figure 28].

[*Figure 28.* Multiple joint systems in curved configuration]

The most successful results came from the PolyFlex™ FDM printed joint, which created a flexible, poseable jointed limb that was connectable and could use its own friction to hold a pose. The wear and tear of the object did prove to be a factor, as did the definition/surface finish of the final print, especially when combined with a harder, PLA printed cap. Due to the configuration of the layer lines of the material that make up the joint, a tear appeared in the high-stress points of the neck seen in Figure 29.

[*Figure 29.* Tear in neck of FDM flexible print]

Based on the results of this pilot study, the ball and socket joint design is unlikely to be of any use in the fabrication of limbs for rubber-hose style puppets for use in animation, due to its insufficiency in terms of scalability and durability over time. Despite this, the simple design will allow multiple modifications in the design stage in order to adjust and test various 3D printing technologies and materials. The next section documents the process of creating an extensive library of samples that were evaluated for their use, both for further case studies within this study and for future researchers.

4.3 Setting up a System of Logging and Documentation

The initial pilot study confirmed that a single design would not allow for accurate testing of all materials, as each 3D printing technology and material required different tolerance in order to function. For this reason, a log was created to document the iterative changes made throughout the study, as well as capture data including dates, time scales, orders placed, numerical information, analytical/reflective writing, videos, images, and other quantitative/qualitative date (Appendix A.1). A second log was created to analyse each sample and technology, their variable materials, and which versions of designs were used for each result (Appendix A.3). These action-research logs consolidated data findings and proved vital for recalling multiple alterations as the investigation developed.

4.4 Parameters of the Study and Material Selection

The CFPR has both FDM[40] printers, and a Formlabs Form 3 SLA printer.[41] As these machines are used by multiple people for various studies, changing the materials between prints was hard and often not possible. Once FDM technology was exhausted as a viable technology for the study and initial tests had been performed on the SLA printer. Various bureau services were used to test the expanded range of materials and technologies. After discussion with supervisors and numerous bureau services were reviewed, a table of potential printing technologies and materials was created. Table 7 shows all proposed printing technologies and the materials selected for their perceived benefits for both mechanical function and future novel potential for puppet fabrication.

FDM	**SLA**	**SLS**	**MJF**	**SLM / DMLS**	**Loss Wax**
ABS	Grey Resin	PEBA 2301 (Flex)	Nylon	Aluminium	Brass
PLA	Flexible	PA 2200 Nylon		Steel	
PolyFlex™	Durable				
NinjaFlex	Tough				
MIX	Rigid				

[*Table 7.* 3D printed materials to test]

Following on from the initial pilot study, a subsequent flexible FDM material called NinjaFlex was tested, in combination with PolyFlex™, ABS[42] and PLA.[43] As reduced scales proved difficult

[40] A full description of each 3D printing technology can be found in Table 3, section 3.4.6.
[41] Which was purchased towards the end of my study in 2020.
[42] ABS (Acrylonitrile Butadiene Styrene).
[43] PLA (Polylactic Acid).

with FDM technology, other technologies/materials were selected to test variation in sizes. SLA proved to have the broadest range of perceivably advantageous materials, due to the increased accuracy; based on the dimensional tolerance range of ± 0.15% to a lower limit of ± 0.01 mm, a series of iterative designs were required to trial the various materials. SLA does, however, require supports during the printing process, which can cause damage during removal and add to the post-processing time. SLS offered the potential for highly accurate strong parts without the need for any additional supports and without issues regarding printing directly on the bed, allowing for quick and easy assembly. Although MJF technology is prized for its complex colour matrix, colour was not an importance aspect of this enquiry. MJF does not offer a huge range of material choices but its overall strength and widespread use within various industries made it a valuable material to sample.

SLM and DMLS are used to print an impressive range of metal alloy materials, an area of increasing interest within a broad range of industries. However, the initial cost per part was deemed prohibitive and thus outside of the investigation's parameters. Additionally, as the future focus of this study is weighted more on the auteur and independent film-making process, it was unlikely that any potential collaborators moving forward would have the financial or creative need to work with these more advanced materials.[44] After the materials were selected, the process of iterative cycle of designing, printing, testing and evaluating each material began, to create a library of samples that could be used to test the functionality, finish and novel visual potential.

4.5 Iterative Design for Different Technologies and Materials Analysis

The initial design phase sought to address potential changes and suggestions highlighted during the pilot study. This involved developing various strategies for printing using different FDM machines and materials. A range of FDM machines were used to allow for flexible and mixed filament printing. After redeveloping the joint design, NinjaFlex flexible filament was trialled, which resulted in a slightly better overall look and finish.

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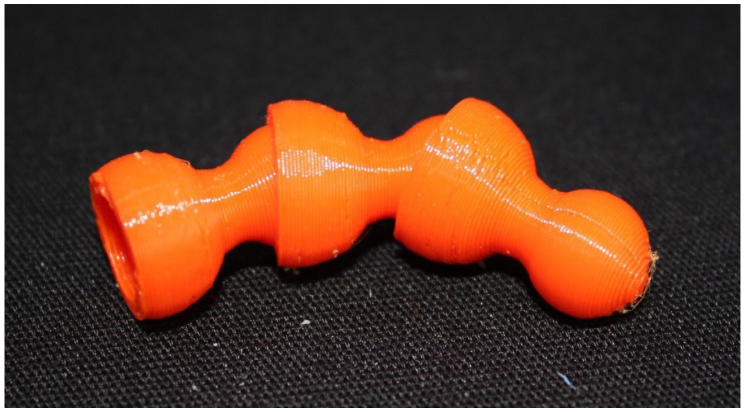
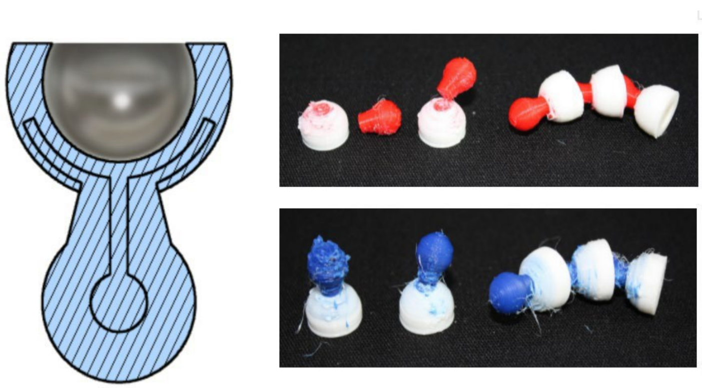
[44] As an alternative to metal printing, a lost-wax process most often employed within the bespoke jewellery-making industry, using SLA wax compounds can be used to cast in various precious metals. An opportunity arose within the department to trial the lost wax process with support from fellow researcher Sofie Boons, a jewellery maker well-versed in the printing and casting process, who was able to produce samples from my designs via an outsourced casting studio.



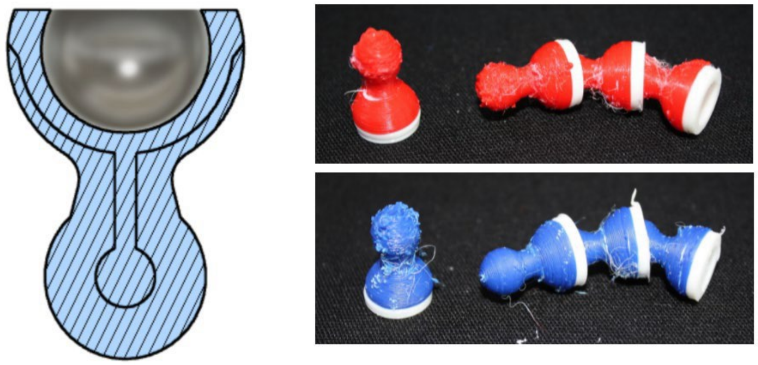
[*Figure 30. FDM printed joint in NinjaFlex flexible filament.*]

Following this, a series of mixed-material tests were produced to trial methods of incorporating both a flexible (PolyFlex™) and solid (PLA/ABS) into a single design through the printer. This was done using a dual extrusion printer, the RoboxPro, which enables two materials to be sliced and printed layer by layer into a single printed part. PolyFlex™ was selected as the flexible material due to its compatibility with both PLA and ABS. A design was created to separate the ball and the neck [Figure 31], the interconnected parts made of two materials reduce the potential of the materials separating or breaking. The joint was tested in both ABS (blue) and PLA (red). The joints that did fit together did not hold, and the brittleness of the neck remained a factor.



[*Figure 31.* Cross-section of design for mixed material FDM printing]

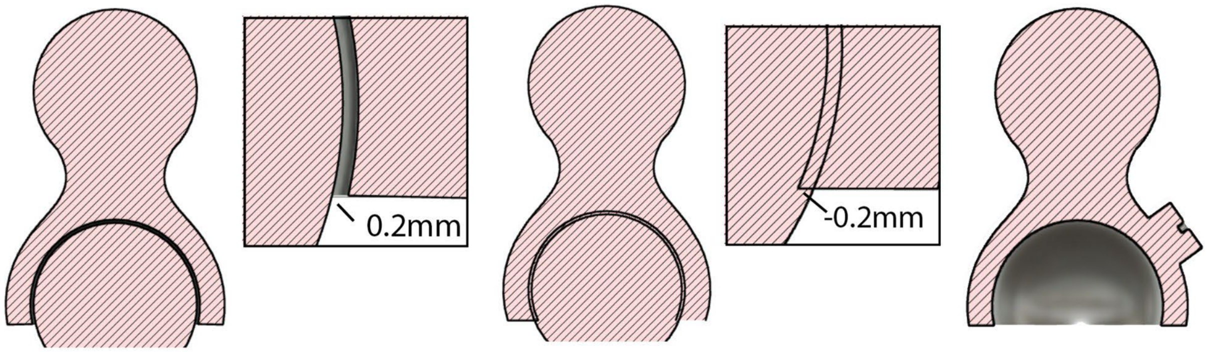
A second test was created in reverse combination with the PLA/ABS being used for the cup and the PolyFlex for the ball and neck, but once printed the parts were unable to fit together. A new design was created to strengthen the neck by incorporating it more fully over the cup [Figure 32]. The hold did not improve significantly.



[*Figure 32.* Second cross-section of design for mixed material FDM printing]

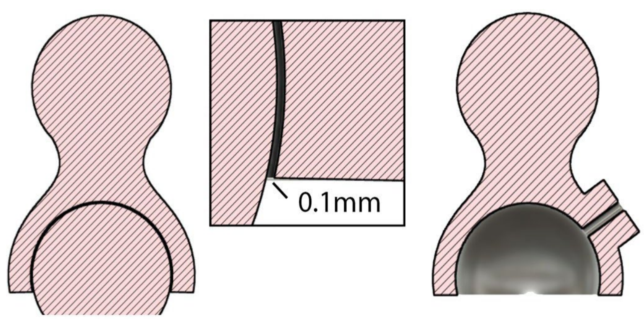
At this stage, the use of FDM technology and its materials was concluded due to the finish quality, accuracy, and scale achievable. In order to engage with the various technologies and materials going forward, the joint design needed to be altered to consider tolerances, scales, and support material requirements. A single design cannot be created to test all materials. Instead, an easily scalable and altered joint was considered; three scales were created, reducing the overall size by half each time to a scale of 0.8 and 0.55. The largest of the set had a tolerance space between ball and cup of 0.2mm, with a secondary version of the design created with -0.2mm tolerance creating an overlap; this was done to create a tighter fit for samples created in flexible or elasticated materials. A third design of the largest scale was created to incorporate a sprue or tap, to be tapped post-printing for the addition of a grub screw for additional tensioning post print [Figure 33][11].

[11] This was only considered for the largest scale; the smaller scales would most likely have broken due to the relative thickness of their cup walls.



[*Figure 33.* Initial largest scale samples of each joint, with 0.2mm tolerance, -0.2 tolerance and tap for post print tapping for addition of grub screw and tensioning]

Initial tests of the three full joints, 0.8 scale and 0.55 scale were created in standard grey resin with the Formlabs SLA printer based at the CFPR. The samples provided a reasonable result and all joints snapped together well. However, to create a better hold moving forward, the tolerance between the cup and socket was reduced further to 0.1mm. The tap was insufficient for tapping, the circumference of the tap was increased, and a hole was added through the entire body to aid in tapping post print [Figure 34].[45]



[*Figure 34.* Revised design reducing tolerance to 0.1mm for full scale joint and altered design for tap version of joint with a larger tap and whole placed fully through the joint]

[45] The original tap design [Figure 33] was used for lost-wax casting samples using brass, as only the largest scale was likely to survive the casting process and the tap/sprue would be used to pour the molten material into the cast. The lost-wax results were unsatisfactory; the process was uneven and created multiple anomalies to the shape and structure of the pieces. The parts were heavy, unable to fit together, and required significant post-processing if any functionality were to be found at all. Unless an individual had the skill, equipment, and knowledge to forge the parts cleanly directly under the guidance of the researcher, this process was unlikely to result in functional parts. Any further testing was deemed unnecessary and outside of the scope of this study. There may be applications for this process if brass or other smelting material were of intrinsic importance to the function or visuals of an object, but this is unlikely to be for functional moving/mechanical parts.

The revised designs were sent to two external bureau services for initial tests using SLA, SLS, and MJF machines. These were done concurrently, due to the lead time for various bureau services and to leverage findings from each technology and material to aid in the development of higher quality samples. SLA samples using Formlabs' Durable and Flexible resin were created in the three scales of the flexible design. The Durable results were inconclusive at this stage as the material had less elasticity than initially thought and did not snap together. The Flexible resin snapped together creating a good hold; if overextended it would come apart, which could be addressed by extending the length of the cup, but this would reduce the possibilities for rotation and positioning through the system. The overall hold of each system did reduce as the scale decreased. However, the material proved satisfactory overall, creating samples that demonstrated the potential benefits of this material for future applications.

In discussion with the service providing both the SLS and MJF samples, a connecting rod was added between each of the joints at each scale and design, to group them together during the printing process. The outer wall of the smaller scale joints was increased—improving its ability to survive the printing process—to 1mm.[46] Initial SLS samples were created in PEBA 2301 and PA 2200 Nylon yielded equally interesting results. PEBA 2301 was a denser, flexible material that allowed the design to snap together, hold, and remain aloft; the durability offered benefits over the inflexible material, creating a strong sample. The material has a powdery, grainy finish but retained comparable strength and quality at reduced scales. With the solid PA 2200 Nylon material, samples also snapped together and retained full rotation at every scale. The new tap design enabled a grub screw to be added, but due to the angle it pushed the ball out of position, dislodging it from the cup housing. An amended design was created to move the tap closer to a 90° angle so the pressure would be placed at the central point of the ball.

Due to the finer detail quality of SLS technology, it was decided that all parts would benefit from a reduced tolerance spacing, an elongation of the cup length, or both. At this stage, the flexible material offered good results, so no further samples were to be created for this material. However, as small revisions were needed to gain better results with the solid PA 2200 Nylon material, further sampling was beneficial and was incorporated into the next round of SLA samples in solid materials, as comparable levels of detail were found between the technologies.

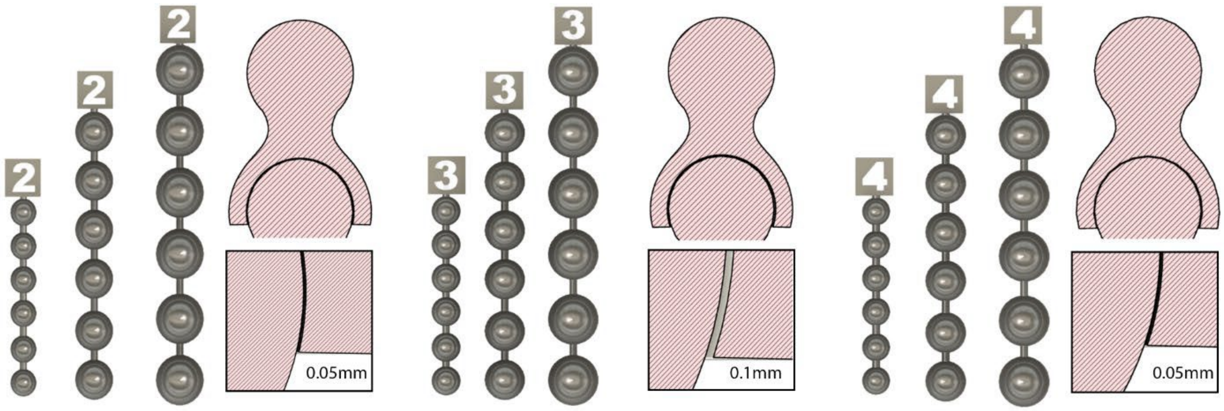
[46] Previously the 0.55 scale's cup wall thickness was 0.8mm.

The MJF samples fit together but did not hold; the tapped version was easily assembled but suffered from the same issue as those created in the PA 2200 SLS material regarding the angle of the tap failing to create a hold. A second sample of the material went through an additional process to remove all excess powder from the surface of the piece.[47] This led to further reductions in the hold, as the overall parts size was reduced. This highlighted the potential risk of SLS and MJF mechanical part becoming less functional over time as the uncured layer of powder on the surface will wear away through use. Overall, the MJF samples were unsuccessful but yielded similar results as the SLS tests. Moving forward it was decided that any changes to design and samples created for the SLS material would likely yield similar results to the MJF. As such, no further investigation of MJF materials or technology were required.

4.6 Final Design Stage and Material Analysis

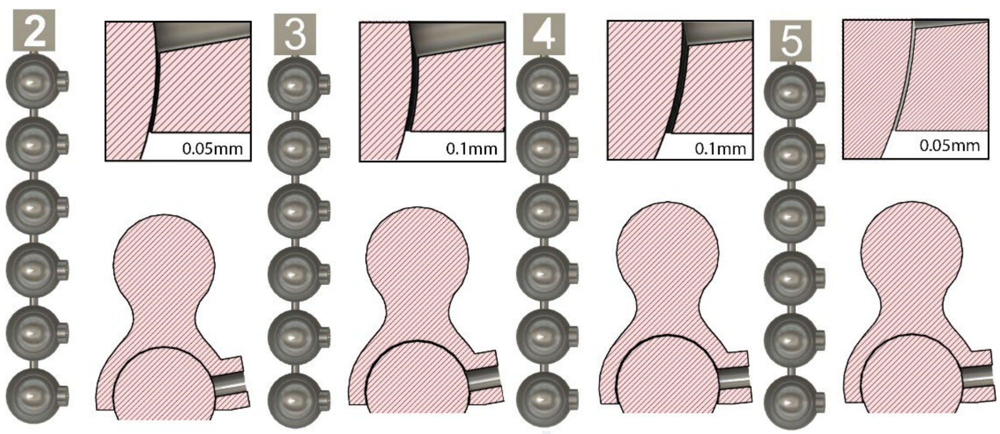
A final round of designs was created, both to yield better results of the SLS PA 2200 materials which had provided the best results so far, and to provide better sample parts for the remaining materials selected by the researcher for SLA printing samples. A series of iterative changes, based on the results found in the previous cycle, were created to achieve the best possible result. Three alternate designs were created for each scale of the joint: versions 2 had the overall tolerance reduced by half, bringing the spacing from 0.1 to 0.05mm in the largest scale; version 3 had an increased cup length, adding an additional 0.5mm to the largest scale version; and version 4 combined both changes, reducing both the tolerance by half and increasing the cup length by 0.5 for the largest version. All changes were converted into the 0.8 and 0.55 scale accordingly [Figure 35].

[47] This post process was only possible for the largest of the samples as the company could not guarantee the survival or retrieval of the 0.8 and 0.55 samples.



[*Figure 35.* Final designs for version 2, 3, and 4 for the scaled joint system]

The tap version followed the same changes, but the position of the tap was also lowered, so pressure could be applied to the centre of the ball once a grub screw was added post print. Version 3 changed tap position, but all other tolerance and design attributes remained the same as the previous design [Figure 36].



[*Figure 36.* Final design for version 2, 3, 4 and 5 for joint system with tap]

As these incremental changes would be printed by an external service, possibly with other objects, the grouped joints had an additional tab added to each of the grouped designs to help identify them after printing. During the SLS process all samples were printed in the same material, so each iterative change in design was assigned a colour to help identify them once removed from their connecting rod (as explained in Table 8).

Full scale joint		Full scale joint with tap	
Version 2 (Yellow)	Tolerance reduced by half (0.05)	Version 2 (Yellow)	Change of tap position and tolerance reduced to 0.05mm
Version 3 (Green)	Cup length increased by 0.5mm	Version 3 (Red)	Change of tap position with no other changes
Version 4 (Blue)	Tolerance reduced by half and cup length increased by 0.5mm	Version 4 (Green)	Change of tap position and cup length increased by 0.5mm
		Version 5 (Blue)	Change of tap position and tolerance reduced by half and cup length increased by 0.5mm
0.8 Scale joint		**0.55 Scale joint**	
Version 2 (Yellow)	Tolerance reduced to scaled half	Version 2 (Yellow)	Tolerance reduced to scaled half
Version 3 (Green)	Cup length increased	Version 3 (Green)	Cup length increased
Version 4 (Blue)	Tolerance reduced by half and cup length increased	Version 4 (Blue)	Tolerance reduced by half and cup length increased

[*Table 8.* Iterative changes and colour identification.]

Version 3 proved to be the most successful design across all scales of the un-tapped design. Version 4 had a reduced hold, despite expectations for it to give the best overall performance, as it combined both the reduced tolerance of version 2 and the extended cup of version 3. After reviewing the design and data log to assure no mistakes had been made, it was believed that version 4 could have been printed on a different machine or with newer/older materials that could account for the minor anomalies in tolerance. The tapped joint versions 4 and 5 yielded similar results with the adjustment to the angle allowing for an increased hold and tensioning of each joint, providing a successful result for increase rigidity and stability over time.

As a satisfactory conclusion had been found through the analysis of the new SLS PA 2200 Nylon samples, these results were used to identify which design were to be used for the last SLA resin sample. It was decided that versions 3 and 4 of each scale joint system and versions 4 and 5 of the tapped joint system would be created in Formlabs' Tough 2K resin, before the final samples were created. The Tough 2K material provided the best results overall. The material, although solid, had a slight rubberised feel, which gave the ideal level of rigidity and hold. At all scales the parts snapped together easily and were rotatable, resulting in a good hold that was able to remain aloft. Version 3 offered the best result in both the full scale and 0.8 scale joint. At the 0.55 scale the overall performance reduced in both version 3 and 4 of the design. It has proven difficult to reach a satisfactory result for this scale of the joint systems, as the scale reduces the overall performance and strength of each piece. For the tapped joint, version 5 proved to be the best overall design for this system, resulting as it did in good movement and hold, with full rigidity once tensioned with the grub screw.

For the final samples, version 3 was selected for both the largest scale and 0.8 scale, versions 3 and 4 were used for 0.55 scale, and version 5 was selected for the tapped version of the joint. The final samples were created using Formlabs' Durable and Rigid 10K resins. The durable material was able to snap together with the new version 3 design at all scales and was also functional in version 4 of the 0.55 scale. The joints were able to rotate and hold themselves aloft, but the overall hold was not strong; the Rigid 10K samples proved to be unsuccessful and were unable to snap together. The material also had a chalky texture and, when forced, the 0.55 scale version 4 broke. It was determined that this material, while very strong, was not appropriate for this study or function.

4.7 Evaluation and Next Steps

For this system of joint, the SLS PA Nylon and the Formlabs Tough 2K resin proved to be the best materials in terms of function, durability, and material strength. Moving forward, this sample library will aid in providing a solid base knowledge of available 3D printing materials for myself and future collaborators. Through its development I have increased my own tacit knowledge of these materials and skills in design that will allow me to engage on a deeper level with the considerations and potential of 3D printers and there materials, as well as those working with them. This pilot study has been vital in increasing my skills regarding the machines, materials, software, and ways of designing using CAD. Along with the research outlined in chapter three, this investigation has so far led to an empirical understanding of the technology at the centre of my research. Without the development of praxis, both within my own field of animation and my newly assimilated understanding of 3D printing, the study would remain purely theoretical; by developing my research using practice I am able to bring new levels of complexity and considerations to the theoretical framework and strive for a better level of understanding throughout my study for myself and the reader.

Chapter 5. Authorship and Labour

This chapter will focus on stop-motion production at different scales; predominately larger studios that produce features or commercials, and the work of ultra-auteurs[48] who produce most creative aspects of their films themselves, such as writing, designing, fabrication, animation and editing. These two extremes represent the clearest distinctions between the authorial potential, labour, and creative control that 3D printing can offer. The concept of authorship here is not in reference to how audiences or readers of a film may apply authorship of a film to an individual but addresses the implicit levels of authorship and control afforded a crew's individual artists and craftspeople across different levels of production. By exploring authorship in film studies and animation production through above- and below-the-line labour, we can trace how 3D printing has increased the number of roles within stop-motion production, affecting division of labour and individual levels of control.

5.1 Authorship in Cinema

Authorship within cinema studies is both complex and controversial. The romantic notion of the author perpetuates the idea of an individual—normally the director—having an almost omnipotent level of control over any given cinematic work. Stemming from literary origins, the idea of the author as creative owner over a work was developed to lend artistic credibility to cinema. In the beginning, films were originally marketed on their prevailing technologies, rarely considering the people behind the screen (Gunning, 1994:42). During the silent era, directors were considered the prominent voice of film over the screenwriter, due to their clear visual presence on screen (Sellors, 2010:3), an idea that was promoted through the critical cinematic debate of the time. Alexandre Astruc's 1948 essay "The birth of a new avant-garde: *La caméra-stylo*" argued for film to be considered as an art form in its own right, by proclaiming the concept

[48] 'Ultra-auteur' is a term coined by the researcher; the 'ultra' prefix here means 'beyond' or 'in excess'. The term follows on from those used by Paul Wells in his 2002 book *Animation: Genre and Authorship* in which he defines Walt Disney as a "supra-auteur" and Ray Harryhausen as an "intra-auteur" (Wells, 2002:101). 'Ultra-auteur' is an addendum to Well's third example, Caroline Leaf, who he defines as an "Avant-Guard, experimental film-maker, working largely independently, and with a more specifically self-conscious auteurism perspective" (Wells, 2002: 101). I suggest ultra-auteur as a way to define filmmakers who make work and can be seen as the key figure of the work, who's labour is attached to all areas of the animated production and makes up the whole of the project, largely by themselves. This definition will become important as we move further into the chapter and the subsequent case study.

of the *caméra-stylo* or 'camera pen' and drawing further links between filmmaker and literary author (Sellors, 2010:11–13).[49]

There are fundamental issues with the idea that the director, as an author, should claim full authorial creative control over any given work—especially when considering the highly collaborative medium of larger Hollywood film productions—but also in the way a film is read and understood as the singular vision of one godlike entity. As Edward Buscombe notes, "what seems to lie behind such a statement is the notion of the 'divine spark' which separates the artist from the ordinary mortals, which divides the genius from the journeyman" (Buscombe, 1973). The assertion of auteur criticism as a theory for signifying the quality of a film by linking it with individual creators moves film criticism towards a structuralist and then post-structuralist approach to film readership, predicated on the structuralist ideas of semiotics; as criticism based on elements, symbols, and recognisable themes of a film and not purely of the conscious authorial voice of the author. In his book *Signs and Meanings in the Cinema* (1972), Peter Wollen suggests that although a film or "text" is "produced by an individual", said individual "does not simply represent or express the author's ideas but exists in its own right". Although the filmmaker as creator is still anchored in the filmic text, there are unconscious elements that should be looked at critically, thus changing the perception of how a film is understood, shifting focus from author to reader (Sellors, 2010:24–32).

Much of the debate focuses on establishing methods for reading, understanding, and developing film criticism. "Author post-structuralism", as exemplified by Ronald Barthes's essay "The death of the author", seeks to remove the author entirely (1967). Michael Foucault's "author function" in "What is an author?" (1969) suggests discourse around an author's work supersedes them as people. Neither of these fit perfectly into all perceivable forms of film-making productions or films as texts. John Caughie encourages the dual concepts of "the fiction

[49] Writers and critics of the French film magazine *Cahiers du Cinéma* continued to push the idea of the cinematic author. In his 1954 essay "A certain tendency in French cinema", noted contributor François Truffaut further distinguished the presence of the cinematic author or 'auteur' who through their distinctive voice creates cinematic works of artistry. Alternatively, a director who simply films a scenario or represents the work of another, without a singular authorial voice, is defined as a *metteur-en-scéne* or scene-setter. This was done to give further authorial claim to the perceived authors at the centre of the film by allowing assertions that the voice of the auteur may achieve a 'better', more artistic film. This assertion was lent further credence by American film critic Andrew Sarris in "Notes on the auteur theory in 1962", which he used to define and develop an 'auteur theory'—one that in 1962 he would go on to describe as "not so much a theory as an attitude, a table of values that converts film history into directorial autobiography" (Sarris, 1962).

of author" and "the authors of the fiction" as a way of considering both ideologies together in reading cinematic work:

> The author, then, both as a possible subject of the enunciation and a sexual, social, historical subject, does indeed have a place in the theory. The insistence on holding together the notion of the author as a subject position constructed in the film's performance, the notion of the authorial code as another text determining our reading and our recognition and the notion of the author as a subject of other practices and formation—that is to say "the fiction of author" and "the authors of the fiction"—is precisely to break the autonomous coherence of each: to break the coherence of the tax as you're "inside" (producing itself, for an empty spectator, out of its own internal operations), or as a pure "outside" (given by the original source), and to attempt to formulate the text, and its subjects, as a movement between the two, or as the involvement of the one in the other, destroying the purity of each. (Caughie, 1981:206)

These and other theoretical positions can be used to understand the possible ways an author influences or is influenced, consciously or unconsciously, by social, sexual and/or economic positions, and how they present this to audiences through the screen—or how the audience's own bias, conscious and unconscious, affects the reading of film or body of work by an auteur. What remains is an inescapable need for an author of some kind to exist—at least in part, either from a historical or critical perspective. What should also be addressed are the levels of labour and individual measures of creativity and control—particularly in the field of animation—propagating the concept of individual layers of authorship within collaborative productions.

5.2 Animation Authorship and Labour

Animation is probably the ultimate "auteurist" cinema.
(Schneider, 1988:30)

Animation pushes the concept of authorship to extremes; at one end, larger commercial studios, such as Disney or LAIKA, are hyper-collaborative and include crew as specialised as hair-and-fur-fabricator all the way up to the seemingly omnipotent director (generally tasked with overviewing/controlling all aspects of production). At the other end, animation can lay claim to the most truthful and exacting embodiment of auteurism in that of the avant-garde or *ultra-auteur* filmmaker who works independently or with few key collaborators, creating work with a singular voice. In these seemingly disparate ways, the labour of animation's creation adds further complexity not only to the idea of authorship in both above- and below-the-line labour, but also how each individual may derive their own level of authorship and creative control over the minutiae of their dedicated area of work.

Generally, larger studios scale their workforce according to the amount of work at any one time; multiple roles are filled by highly skilled individuals hired, potentially, for a single purpose over an extended period. These roles sit within a hierarchy of above- and below-the-line labour. Sabine Heller describes below-the-line (BTL) as those often seen as technical crew, unable to "claim individual credit" or "intellectual property rights" within the industry.[50] Above-the-line (ATL) crew are defined as "creative personnel"—such as "directors, producers and writers"—who can "claim creative agency and are acknowledged as authors within and outside of industry" (Heller, 2019:2). Heller goes on to identify levels of the authorial claim within the CGI pipeline in conversation with members of the industry. John T. Caldwell explores (2013) in detail the below-the-line authorship in live-action filmmaking and the historic issues that "stripping" of intellectual property (IP) ownership (through "work for hire" contracts) have created for both ATL and BTL workers. However, whilst ATL personnel can negotiate higher pay and potential individual residual payments, any residual owed to BTL workers will largely be paid into unions (Caldwell, 2013: 353–54). Caldwell goes on to explain how, like academics and critics, the Hollywood system continues to promote the idea of the singular author as visionary, through the use of behind-the-scenes footage or interviews with ATL directors to further their position as the true author of a work (350–52).[51] The use of "strategic authorship control schemes" (SACS) that serve to develop "totalitarian" control over each stage of the production process, is an explicit method to keep the authorial control above the line. However, BTL crew can use modes of "tactical authorial counter pressures" (TACP) such as "gap filling" and "problem-solving" that require BTL crew to "creatively" engage or "solve" issues as they arise (361–63). Live-action and animated film productions rely on levels of "function autonomy" that Stahl (2005) describes as the way a craftsperson's "superior knowledge" is derived through "self-direction" and the "direction of others at work" towards individual "moment[s] of authorship which also provided workers with satisfaction and continued enjoyment in their work" (2005, citing Montgomery 1979).

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[50] Heller uses the animators as an example of BTL crew, but later queries this decision.
[51] Stahl also documented how the combination of IP residual and reuse royalties "reinforce" ideas of above- and below-the-line labour authorship, by determining that individual residuals denote ATL crew as uniquely talented, whilst "collective residuals" for BTL workers "reinforces the authorship on both sides of the line" (Stahl, 2015:95–9).

The director's vision or concept for production is dependent on each crewmember, particularly the skills and knowledge of BTL practitioners. Most directors do not possess every skill required to create a film at a commercial level, nor the time to make it single-handedly. Many directors openly admit this and are quick to assign credit to the highly skilled personnel below this invisible line. Director Johnny Kelly often works with multiple crewmembers for fast-paced advertisement campaigns:

> If someone compliments me on a project, I always feel I can't say thank you. [...] When it comes to [commercial work] I almost feel like I have to say something like, we were just really lucky to have such a lovely team. It's a collaboration with a lot of people on a lot of these projects. So, I do feel uncomfortable. [...] On Vimeo, […] [I will name] every single person, to the extent that Nexus would actually say, "can you take off people? You know, we're not supposed to mention catering". But catering is a crucial part.[52]

The desire for an authorial claim by BTL crew members may have less to do with the need to assert control over a given aspect of production and more with gathering evidence for future showreels/portfolios (Caldwell, 2013: 366–67). Stahl (2005) in conversation with a storyboard artist, notes how their "experience working from [an] outline", as a more creatively freeform method of working (compared to simply translating a series of images) "stood out most in her portfolio"; the inherent authorial value in her work moved her directly to her next role (102). Caldwell also suggests that BTL crew publicly promoting their own work online may "undercut" or "scatter" the authorial claim of the ATL members. This could be seen as a form of what Stahl (205) refers to as "economic exploitation", through which BTL workers are used in promotional materials (such as DVD extras) to add value to the overall production but are rarely compensated financially for such appearances. I would suggest, however, that this is simply a by-product of working in the creative industries, perceived by all crew as mutually beneficial. As Kelly confirms:

> You have to put yourself out there as a freelancing director to get more work. But […] [also make] sure that you're crediting everyone. Partly because they're due the credit, and partly because you want to work with them again. If you run off and say, "I'm amazing; what a genius I am", then people aren't going to answer your calls the next time.[53]

[52] Interview with Johnny Kelly, personal communication,19th February 2020
[53] Interview with Johnny Kelly, personal communication,19th February 2020

Due to the larger concern of IP and assigning the authorial claim to individuals to aid with distribution, the enjoyment of creative work is often overlooked. However, in an industry that is often described as competitive due to fluctuation in available work, a continued interest in a career in this industry is most prominently placed on a desire for creative exploration, skill achievement and joy. As Heller (2019) notes, many of her interview subjects cited a "desire to contribute creatively" to their work, referring to both "freedom" and "agency" as "gratifying" elements.[54] Caldwell (2013) suggests that a move away from "textual analysis" and "philosophical speculation" towards fieldwork within the industry itself may prove more beneficial in actually decoding/deciphering layers of authorship within the system that continue to confuse those working outside (362). In this way, I seek to not only look at public records of the crew as found in film credits and promotional videos but conduct interviews with those working in positions affected by the ever-changing working methods specific to that of 3D printing.

5.3 New Departments

The complexity of animation authorship is not only in the scale of production but the number of roles that offer potential authorial control. The director is a highly skilled and knowledgeable individual whose core strength lies in their ability to see the bigger picture, overseeing and making decisions when there is not necessarily a clearly defined right or wrong. To see them as the singular authorial component of a film is understandable as they make many of the creative decisions and can also hold multiple roles within production, including writer, animator and/or designer.[55] However, within the hierarchy of animation production, directors often work with one or more animation directors or supervisors, who work closely with animators on set (Careers in Screen, 2020). Animators in senior, junior, assistant, or trainee roles are often thought of as actors who perform through a puppet or digital character and work under the director. However, their performance is reliant on the functionality of those puppets/characters, which is the responsibility of the puppet fabricators, character designers and set/modelmakers. The model, set and puppet fabricators interpret the look of the film by replicating designs either created or signed-off by the director. Modelmakers use their knowledge and experimentations with materials to create objects that are both functional and look convincing. Communication

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[54] Stahl (2015) also states that the artists he spoke to associate the "degree of satisfaction they gained" in their work to the level of "autonomy" they had in the process (103).
[55] Directors also often create—either by themselves or with the help of animation directors/supervisors or animators—reference videos known as LAVS (Live-action video shoot) and extensive performance notes to give to crew, either on set or during reviews.

between directors, animators and puppet/set-makers is required throughout production, in case of breakages or if alterations are needed to provide further movement or easier access for animators working on the set. Each member of a crew is brought in on their own skills and merit.

Animation is the art of motion but also problem-solving, incorporating craft, skills, artistic vision, and communication. Through levels of macro and micromanagement, individual creative decisions, degrees of control and authorship are found. Those involved in the production of a film bring their skills, sensibilities and, more importantly, ideas to the process in order to create the best possible film, both as an expression of pride and for future employment. 3D printing replacements extend this point even further. As with all new technologies, especially those perceived as disruptive, there were concerns that 3D printing may result in job losses.[56] This has proven to be largely untrue, as Brian McLean discusses:

> I can't tell you how many times after a presentation about the RP process somebody asks, “Oh, this must mean you need a lot less people to do this than the traditional, hand-sculpting way.” The answer is, “No, you actually need a lot more people.” “Well then, you must save a lot of time.” Again, the answer is “No.” “Well, it must save money?” “Nope.” And at the end of the day, after you say “No, no, no, it's actually more expensive. You need more people, it takes longer, it's not easier”. They said “Well, why the hell do you do it?” The only answer is because of the creative freedom and performance it allows.[57]

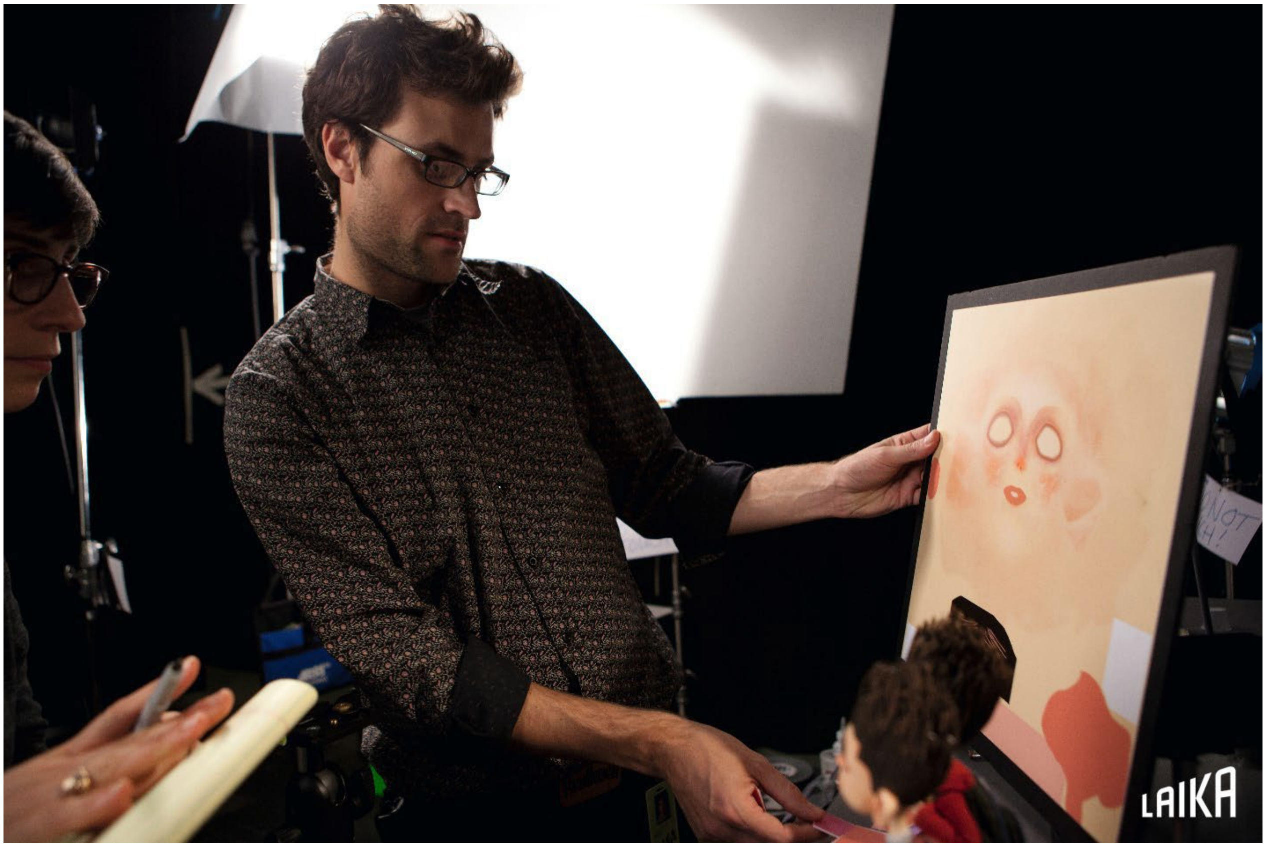
The addition of a rapid prototyping or 3D printing department within the stop-motion pipeline is a relatively recent development; like all departments, its size will depend on production needs, but it has assuredly increased the labour and complexity of animation. With the advent of 3D printing, studios such as LAIKA now have a dedicated replacement animation and engineering department, in which there are numerous new roles.[58] Although CGI animators have been employed in the past to create special effects, set extensions and crowds, within rapid prototyping departments the combining of techniques has taken on greater levels of synergy.

[56] As discussed in section 3.2.

[57] Interview with Brian McLean, personal communication, 6th April 2020

[58] These roles include RP production manager, fabrication design lead, fabrication performance lead, technical director, assistant technical director, technical director of facial rigging, CG facial riggers, CG facial rigging intern, lead CG modeller, CG modellers, lead texture artist, texture artist, RP coordinator, reproduction assistant, face processing and testing leads, replacement animation specialist, replacement animation testers, lead 3D printer technician, 3D printer technician, RP fabricators, junior RP fabricator, quality assurance lead and quality assurance trainers. This list of roles was taken from the credit list of *Missing Link* (2019), the most recent LAIKA film at the time of writing (laika.com, 2019).

Similar to the role of character technical director, described by Heller (2013) as providing the tools for efficient performances to the animators (3), puppet fabricators, although not involved with the delivery of the final performance, use their skills in selecting the best possible material to suit the look and performance of the puppet, giving them authorial claim over the final look and movement of the puppet on set.[59]



[*Figure 37*. Brian McLean on set. *Image used with Special Thanks to LAIKA Studios*]

5.4 Added Complexity and Performance

Replacement animation is perhaps most associated with George Pal, who intricately designed all replacement parts himself before they were manufactured by a team of craftspeople. 3D printing is predominately used for replacement animation, pioneered by LAIKA after months of

[59] Priebe (2010) states, "The amount of sculpting and modelling that went into the film [*Coraline*] was estimated to be the equivalent of nearly 30 years of traditional sculpting; rapid prototyping allowed this amount to be completed in about 18 months" (142). This statement fails to acknowledge, however, that had this original time estimation for traditional process been true, an alternative method of facial animation would have been selected (something that is explored further in section 7.5).

research and development.[60] The considerations of the process regarding authorship are multifaceted; to understand these issues one needs to broach them from the personal or creative perspective of those directly involved in the process. Whilst the director is arguably focused on telling the story in the best way possible, the animation director is focused on getting the best performance out of the animator. The animator, in turn, is focused on producing this for the director. Animators often work from reference performances called live-action video or LAVs to create the most impactful or naturalistic performance possible; this is largely determined by the posing and timing of the body's performance, while facial performance is key in close-up shots. These LAVs can be created by the animators themselves (or sometimes by the animation director or lead director) to get across the movement, staging, mood or timing required in a scene. 3D printed replacements are essentially the printing of individual frames of a CG animated sequence that are then placed frame-by-frame onto the character during the animator's performance. McLean outlines the increased complexity for animators through this process:

> [In] previous movies that used replacement animation, the limited number of facial expressions meant that an animator could just go out on set with their box of hand-sculpted faces and, animating on the fly, […] swapping out a different face, seeing if it worked. They had the […] puzzle pieces right there that they could put together. But as we were discovering that we could produce more and more of these puzzle pieces, that meant that suddenly […] animators [...] would go out to set with hundreds of faces in a box and they didn't know what the hell they were. It was much more complicated. So, we now needed to […] provide them with specific faces. We needed to give them a more whittled down box of faces instead of providing them with faces they needed based on the X sheet, but also additional faces in case they wanted to experiment during a shot. We wanted to give them flexibility. But that meant that instead of going out with 100 faces, they suddenly had 250 out there and it became too daunting. We then said we'd only give the stage animator exactly the faces that they'd need.[61]

The complexity and sheer volume of potential faces, although exciting in its ability to deliver greater nuance or a more exaggerated performance, requires logical considerations to complement the collaborative voice of the director, CG animator and stop-motion animator to give the best possible performance. McLean continues:

> In previous films, there was a combination of reusing facial expressions with those kits. And by doing that, the animator sort of got used to different facial expressions […] and they would know what worked and know what to ask for. It's always a collaboration,

[60] Further description of the process can be found in chapter 2, section 2.1–2.2.2.
[61] Interview with Brian McLean, personal correspondence, 6th April 2020

> but it was something that became user-readable. The codes on the back were something that the animators could understand.[62]

The need to constantly balance the various authorial voices involved in the creation of replacement faces to this level is something that is constantly being addressed at LAIKA, as McLean acknowledges:

> As we moved to shots specific […] facial animation it meant that the performances were more locked in. We were producing different facial expressions for almost every frame in a shot. So, it gave them less flexibility to deviate from the Director-approved facial performance. Looking back, *Coraline* was relatively simple [...] because we did this linear process from sculpt all the way to animation. [...] When we started using colour printing on *ParaNorman* was where we were able to discover a way to make it a little bit more […] streamlined. […] CG modellers, riggers, animators, and texture painters could all be […] working on the same asset at the same time. We devised a workflow that made us more nimble […] [and] able to change things if needed.[63]

Justin Rasch, who holds the unusual position of being both a highly talented CG and stop-motion animator, has previously worked on both *Coraline* and *Kubo and The Two Strings* as a stop-motion animator at LAIKA. Having an insight into both the CG and stop-motion performance provides insight into the potential pitfalls and benefits that are afforded by combining both through 3D printing. CG animation allows for constant fixes and small incremental changes based on feedback and criticism from multiple members of the crew, which can become frustrating:

> The amount of massaging and nit-picking of shots is through the roof on CG. So, it just takes a lot longer. [...] But […] when you get to that finish line in stop motion, it's done. If it's approved, it's done, which is part of the magic that I love. You get what you get.[64]

The use of CG in creating 3D printed replacements opens stop-motion production up to a similar issue: the notorious 'tweak cycle' found in CG productions[65]. When raised as a potential issue, Rasch agreed, but added:

> Yeah, there definitely is. But I think the people directing stop motion have a different mentality completely, […] it doesn't have to be that level of perfection. If you're a CG

62 Interview with Brian McLean, personal correspondence, 6th April 2020
63 Interview with Brian McLean, personal correspondence, 6th April 2020
64 Interview with Justin Rasch, personal communication, 12th January 2020
65 The 'tweak cycle' refers to the repetitive process of making small changes within production.

> director, […] there's a learning process where you realise you can't do what you want to do [...] because production has to get done.[66]

The practical constraints of printing, post-processing and shooting on a live set may also alleviate the possibility of stumbling into a tweak cycle. Replacement animation is often seen to offer more subtle and nuanced facial changes; the effect 3D printing has on the performance offers unique opportunities for bespoke movement and minute detail, which is a boon for practitioners like Rasch:

> I think it's amazing. I think it's beautiful. […] Being a 2D guy, and then a CG guy, part of the charm is the limitations of stop motion. But at the same time, it's too limited sometimes, and sometimes I just want to get in there and […] [deform] the shapes more and I want to be able to push things. I also just want the tiniest of increment[s] that you can't even see, or my hand can't create by tapping or blowing on the character. So, I love the more refined performances. There is a level that I don't think we have to go […] [too], because I still love the charm of some of the roughness of stop motion. But I just think it's an amazing tool by how big of expression changes we can do, by how you can pre-vis your performances before you really get on set […] it just ups the quality of performance.[67]

[66] Interview with Justin Rasch, personal communication, 12th January 2020
[67] Interview with Justin Rasch, personal communication, 12th January 2020

[*Figure 38.* Library system in use. Image used with Special Thanks to LAIKA Studios]

Caldwell suggests that “new technology” can cause further “delegation of artistic agency” (Caldwell, 2013:361). In this way, the division of labour required to create the multiple parts dilutes control and further fragments ownership over a performance. As Rasch recounts below, the continuous increase in faces has led to some members of production having more control over their contribution to a film, whilst reducing that of others:

> It's another step of someone else coming in and giving you their piece of the performance, so [the CGI facial animators] get a lot more ownership now over the facial performance than they used to when we were remotely controlling them to create a performance that we wanted as an animator. […] I understand that coolness […] [as they can now say they] own that face, but I personally wouldn't want that in my own work. I've worked on projects where we just have kits, […] [and we just] grab as we animate, […] then you get the little joy of seeing the performance happen as you're animating and tweaking. I'm not saying that stop-motion animators can't go back if they don't agree with something that they get delivered. They can go back and [ask to] change this a little bit and […] get a new library delivery, but I think, when [...] the directors already bought off

> on a facial performance, more often than not, you just go with it unless there's a problem.[68]

A balance can be maintained if lines of communication are kept open and there is the ability to make changes throughout the performance. However, as Rasch acknowledges, ultimately the director's final decision is key. Rasch concludes:

> I think as long as the artist is in the process. [...] Originally you would sit right next to a CG animator [...] and the two of you would craft the performance together. That's how it was on *ParaNorman, Coraline* and *The Boxtrolls*. That started to peel off halfway through *Kubo* [*and the Two Strings*] where the schedule meant just having the CG animators do the facial performance without really communicating with the stop motion animator, and [...] that's not okay with me. I think [...] bodies have to be working together with the facial performance to support each other and to push it. [...] I didn't work on *Missing Link*, so I didn't have to deal with […] [just being] delivered a facial performance, and then […] [having to] make it work. [...] I saw *Missing Link* and it didn't look disconnected. But I personally think that the CG and stop-motion animators have to work together and be involved, to really get the best work.[69]

Whether these micro tweaks have any notable effect on the final film is debatable, but there is still a need to consider the individual ability of each animator involved in the creation of a performance. As Rasch highlights, although 3D printing offers the potential for nuanced performance there are also the considerations of individual taste and choice. As Merlin Crossingham, creative director at Bristol-based Aardman Studios, expresses:

> Personally, I think unless the animator who is executing the shot has also done the lip sync and the facial expressions pre 3D printing, then it completely neuters their ability to give the character its performance on the screen.[70]

McLean also acknowledges that providing animators on set with only the exact faces necessary loses a certain level of adaptability through the use of pre-constructed facial sets:

> Unfortunately that meant that they lost some flexibility on set which, understandably, was frustrating. Now they were only given what was pre-described and they weren't able to tweak things on set if they wanted to. It was a constant sort of push and pull on how to best support the stage animators and make sure we are supporting them in the pursuit of the best possible animated performances. And I think that still to this day, that's

[68] Interview with Justin Rasch, personal communication, 12th January 2020
[69] Interview with Justin Rasch, personal communication, 12th January 2020
[70] Interview with Merlin Crossingham, personal communication, 7th April 2020

something that we, […] want to make sure that, as we improve this technique of 3D printing facial expressions, that we're not taking away from stop-motion animators.[71]

Despite this understanding, LAIKA's most recent film, *Missing Link* (2019), continued to pursue an increase in unique faces, producing a custom facial animation for every shot of the film. As McLean explains, a different faceplate was being created for almost every frame of a puppet's performance, reverting control back to the director who would approve the digital shot before it was delivered to the animator:

> *Missing Link* was the first film that we were able to produce custom facial animation for every single shot in the film. […] as we moved to shots specific to facial animation it meant that the performances were more locked in. We were producing different facial expressions for almost every frame in a shot. So, it gave them less flexibility to deviate from the Director-approved facial performance.[72]

[*Figure 39.* Crew working on face replacements. Image used with Special Thanks to LAIKA Studios]

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[71] Interview with Brian McLean, personal communication, 6th April 2020
[72] Interview with Brian McLean, personal communication, 6th April 2020

This back and forth to get the best possible performance out of the puppets, although necessary, adds far more complexity to the already multifaceted systems of both replacement and stop-motion animation; a challenge that LAIKA is happy to tackle in their pursuit for hyper-fluid, nuanced performance and perfectly rendered characters that have been engineered and scrutinised down to the individual frame. This way of working does not suit everyone, however, and nor should it. Crossingham states that for him to consider using facial replacement to this level, there would have to be additional consideration given to how the face is positioned regarding camera angles:

> I was offered to work on *The Pirates! In an Adventure with Scientists!* at Aardman [...] and I declined, specifically because of the choice of using 3D printing for the lower half of the face. The top half was clay, the bottom half was 3D printed. Even though they had a wide range of mouths, you could never adjust the frame, specifically to the camera angle. All of the lip-synching was done with the camera straight on. It was never done with a camera that was sympathetic. [...] It really ties one hand behind the back of the animator who is trying to get a very specific, nuanced character performance on screen.[73]

This system would, of course, add even more complexity to an already-complex way of working. He concludes this thought by speculating that if all these things could be addressed, the ever-diluting division of labour and the increased complexity may render the whole process pointless as the CG has either become so prevalent in the production process or has negated the physicality of the stop-motion process:

> While I think it's very clever, and it can give an exquisitely subtle performance. Creatively, I think, in the larger process of a feature film, many people are having to do the jobs for many other people. The process does not allow maximum character performance and I think that's the key. While the movement can be amazing, the character performance [on] screen can only be affected by the process being removed from happening in front of the camera. So, I personally wouldn't choose to either use it as a filmmaking tool or to use it as an animator. Unless you could mimic the camera angle, do the character performance to the camera in CG, then have it printed, then apply to the stop motion. At that point, you have to ask yourself, why are you bothering?[74]

[73] Interview with Merlin Crossingham, personal communication, 7th April 2020
[74] Interview with Merlin Crossingham, personal communication, 7th April 2020

The dilution of performance is a consideration also raised by Johnny Kelly. However, as a director predominantly focused on short, fast-paced advertising campaigns he sees it as potentially beneficial since it allows for moving labour to other areas of production:

> Sometimes it does feel like you're losing a little bit of potential performance […] but I imagine you'll push those resources somewhere else, if it's easier to do the face for example, then it frees you up to put more into the overall physical performance and add more nuance elsewhere. […] It's another way to make a job easier, I suppose. But I guess it's sort of automation, isn't it? The same thing is happening on a macro level.[75]

This back and forth between the increased levels of performance and the potential for a certain element to feel 'automated' due to the division of labour are considerations that bigger commercial studios need to make. Division of labour—and thus the levels of authorship—can be continually debated but ultimately rely on an individual's preference and level of concern. Although worthy of discussion, most if not all crew members are happy to work with this technology to elevate performance; it has also increased the number of roles, and thus improved employability.

[75] Interview with Johnny Kelly, personal communication, 19th February 2020

[*Figure 40*. Animator on set working with faces. Image used with Special Thanks to LAIKA Studios]

5.5 New Opportunity For the Ultra-Auteur

If the use of 3D printing within larger-scale productions can be seen as increasing the autonomy and authorship of both ATL and BTL crewmembers. It is responsible to deduce that 3D printing could offer further control and creative potential to ultra-auteur filmmakers, perhaps more so. Due to the continued development of all technology, access to equipment and the knowledge to make filmic work has increased, allowing for smaller budgets, crews, or auteur ventures to flourish. Greater creative freedom allows for sophisticated and detailed objects to be produced through desktop 3D printers and bureaus. The bespoke nature of both stop-motion and 3D printing offers the potential for complexity, new narratives, and creativity to be put into the hands of the individual filmmaker. As a tool, 3D printing is offering filmmakers unfathomable levels of creative opportunities in addition to its widespread uptake in commercial productions and feature films.

Pam Cook (1977–78) explains how through these smaller “artisanal mode[s] of production” allow filmmakers to retain “control” in all areas of the film's production, noting that the personal or grant-based funding structure these productions rely on often require cheap equipment and labour cost to keep to budget (273). The auteur productions have a far more pronounced “autobiographical”, “poetic” or “epistolary” form, as the filmmaker’s relationship to the work is far more “intimate”. The marginal space they inhabit, outside of mainstream cinema, offers ultimate freedom (274). The potential to witness far more pronounced authorial voices and levels of self-exploration make the avant-garde filmmaking of the ultra-auteur far clearer (281) and easier to study.[76]

3D printing can offer greater creative autonomy to individuals working in the stop-motion process, allowing for further subtlety of movement and control over their work. It could, however, potentially dilute the creative process and create divisions in labour, abstracting the maker from their work and removing both agency and enjoyment of the process. These issues can be alleviated by maintaining an open channel of communication, adapting, and promoting a collaborative expression of creativity to enable the best possible result. To explore how 3D printing could enable greater levels of authorial control and authorial fingerprinting, a case study was developed in collaboration with an ultra-auteur filmmaker, discussed in the next chapter.

[76] In the extreme case of the ultra-auteur filmmaker, the director may very well have written the story, made the sets, props and puppets with some assistance, or by themselves. They may even provide the voice, sound and/or music for the film as well.

Chapter 6. Case Study: Auteur Filmmaker Eye Mechanism—*SHACKLE*

As discussed in section 3.2.1, internal eye mechanisms for stop-motion were first developed by LAIKA for *Coraline* (2009). Subsequently, multiple similar systems have been created both in the industry (stopmotionshop.com, 2020; UPuno.com, 2022), research (Yekti, 2017b) and within online craft communities. This case study explores the design process through its initiation, documentation, and development, using action research in collaboration with an ultra-auteur filmmaker, to document the creative process and explore the authorial potential 3D printing can afford filmmakers.

6.1 Project Outline

An animation duo based in Edinburgh, Ainslie Henderson and Will Anderson have won multiple awards, including the Best Short Animation BAFTA in 2013 for their film *The Making of Longbird*. Well known for their poignant characters, thoughtful storytelling, and experimental approach to filmmaking, they were ideal candidates to approach to collaborate on a film that uses 3D printing in a novel way. Having initially contacted them regarding collaborating on a film reflecting on the aesthetics of 3D printing, the opportunity arose to assist with their use of 3D printing in their upcoming BFI funded film *SHACKLE*.[77] Henderson, who had recently become interested in the use of 3D printing as a way of making, fielded the initial reply. *SHACKLE* required a novel approach to an eye mechanism that could be adapted to three different designs of puppets. Henderson is well known for his craft-centred approach to puppet fabrication, often made using found or organic objects and fibres such as wool, wood, leaves and bark to create beautiful films with poetic imagery. Like many animators (Purves, 2010:100) he believes much of the personality and pathos of a character's performance lies in the eyes:

> It is hugely important, in that this is a film that doesn't have any dialogue in it. There isn't a lot of action so a lot of the emotion and […] dynamic between the characters comes from what they feel about each other […] and how they interact. In that way, it comes down to what they can emote through their eyes. So, I feel like it is really important. There are a lot of close ups, and a lot of them watching each other and reacting to each other, just through their facial expressions. The design of the face is essential to letting me animate that well.[78]

[77] A copy of the initial email sent to collaborators can be found in Appendix B.2.
[78] Interview with Ainslie Henderson, personnel communication, 19th October 2020. Full transcript found in Appendix B.3.

Due to the organic nature of his puppet creation, they are all created in completely different ways, bringing a creative potency to his work. As a maker, however, he finds the lack of a pre-defined method of working difficult when broaching a new project. From this study he also wanted to develop a method of creating eyes that could be repeatable and be applicable for future projects, stating that he “wanted the eyes to become a template, or a foundation that I could then build on and make different styles from”.[79]

The film was also to be shot outside in woodland, employing real environments, lighting, and weather conditions, shooting over a period of a year, to tell a story that made use of the passing seasons. This added further levels of complexity to the film, requiring Henderson to work quickly so lighting and weather conditions did not change dramatically over the span of a shot. This type of filmmaking is rare, particularly when combined with the highly nuanced performance Henderson aimed to achieve through puppet manipulation (rather than replacements, composting, or limiting the outside sequence to simpler action shots). This meant that the eye mechanism would also have to work efficiently and simply so as not to hinder the animation process further:

> I'm going to be working outside, the pressures of working quickly will be huge. […] I've had eyes before where I've had to get pins and put them in and move things. […] it can be really time consuming. You can lose an hour suddenly just finessing things. So, I knew I had to make the eyes easy to work with, quickly and go back to how they were.[80]

As a result of these discussions, it was determined that a case study could be conducted to develop an eye mechanism that would benefit the artist's current film and assist the researcher in investigating the authorial benefits that 3D printing could offer an auteur.

6.1.1 Script and Character Design

I was then sent a script for the film to ascertain the needs and use of the eye mechanism within the story. The tagline for the film is “three archetypal spirits explore the conflicting human drives of creativity, possessiveness and our desire for status” (BFI, 2020). The story, full of metaphor and poetic visualisations of the construction and destruction of creativity, features three

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[79] Interview with Ainslie Henderson, personnel communication, 19th October 2020. Full transcript found in Appendix B.3.
[80] Interview with Ainslie Henderson, personnel communication, 19th October 2020. Full transcript found in Appendix B.3.

characters who are referred to in the script as HE, SHE, and IT. The characters are animalistic creatures that represent the various human drives; IT, for example, is described as cunning and sly, both lizard and rat-like, with slitted cat-like eyes that represent possessiveness and the desire for status. Throughout the film the eyes are used as a visual motif to represent the impulse of all three characters towards a more selfish, reptilian desire that is represented through their obsession over the object of their desire. As the film has no dialogue this is communicated through changes of the iris, which require the internal eyeballs to be replaceable.

There were no character designs as Henderson prefers to feel his way around the puppet, adding to the richness of the puppet layer by layer, in a manner similar to collage. This is unusual, as animated projects typically rely considerably on pre-production materials—including concept sketches, scaled/proportioned designs, and detailed blueprint—to break down construction into various processes. The uniqueness of Henderson's process meant that the puppet would be developed organically around the eyes as the central point of the puppet's fabrication.

6.1.2 Project Aims and Objective

Within the overall study, this case study looks at the concept of authorship, questioning how 3D printers can be used to give greater authorial control to filmmakers who work in an ultra-auteur way. As such, keeping Henderson's authorial voice throughout the process was of utmost importance. I, as researcher, would act as advisor and facilitator of the process, aiding with the technical mechanical components, maintaining, and documenting communication with Henderson at every stage. The aim and objectives for the project can be found in Table 9 and are derived from the requirement discussed in the previous sections.

Aim	The aim of the case study is to work collaboratively with Ainslie to create an eye mechanism at three scales that allows for subtle movement and post-processing customisation, for a short, animated film set in an outside environment.
Objectives	• Create an adaptable eye mechanism that works at three different scales, enclosed within an eye socket with poseable eyelids.

	• Develop a system that efficiently accommodates a stop-motion and real-world shooting environment, allowing for intricate movements that remain static over long periods of time once positioned, and in-shot replacement of the internal eyeball. • Create white hollow spherical eyeballs that allow for internal painting to create depth, with a smooth surface finish. • Spacing and tolerances of each layer needed to allow for further material (i.e., resin and organic covering materials) to be added after printing. • Create an adaptable design that could be used in future projects.

[*Table 9.* Aims and Objectives for Auteur filmmaker eye mechanism – SHACKLE Case Study]

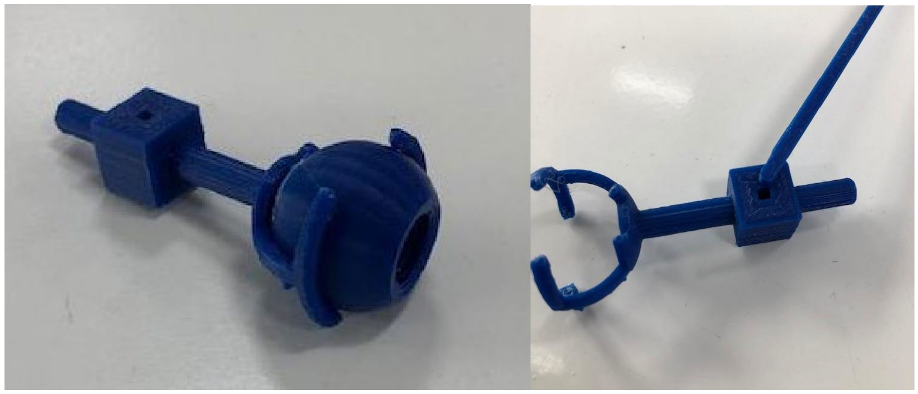
6.2 Development of the Project

To document the case study, extensive notes were kept regarding designs, tests, conversations, and issues that arose during the development of the final objects in a data log (Appendix B.1). Conversations were recorded via email, messaging apps, and video.[81] As well as providing the CAD models, the researcher coordinated the test and printing of final pieces between both the research centre and bureau services. A bureau service was selected after at least three companies were contacted for competitive quotes, based on their availability to do the work, range of materials available, specific printer,[82] and cost. All tests and materials were paid for by the collaborator—Ainslie Henderson—as part of the research and development cost allocated within his funding budget.

6.3 Initial Designs by the Participant

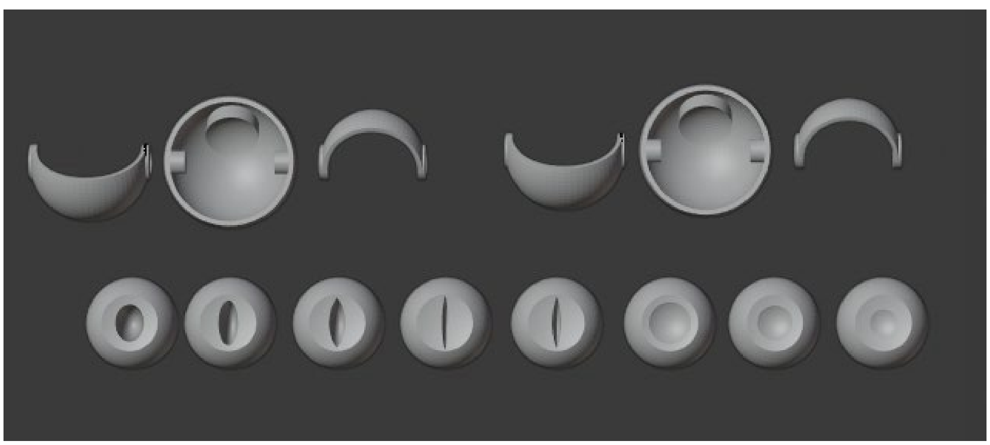
Having recently taught himself the free open-source 3D software Blender, Henderson created an initial design. This initial design once printed using the FDM printing process, proved to be too unstable due to the lack of enclosure for the eyeball and a lack of stability in the stem at the back [Figure 41].

[81] The case study log can be found in Appendix B.1; videos can be found in the materials folder "Appendix_B.1_DataLogVideos" that accompanies this thesis.
[82] The bureau services used Formlabs Form 2 printers.



[*Figure 41.* First design by Ainslie Henderson, FDM printed in PLA]

It was subsequently decided that the eyelid should also be part of the design, at which stage Henderson created a second test, this time with an external cup to house both eyelids and eyeball [Figure 42]. These brackets would allow the eyelids to pivot around the eyeball and the raised bed at the back would keep the eyeball elevated within the socket. This design also included a range of eyeballs that would be swapped in and out of the socket to create the look of dilating and morphing irises in the puppets.



[*Figure 42.* Second design by Ainslie Henderson created in Blender. Image used with thanks to Ainslie Henderson.]

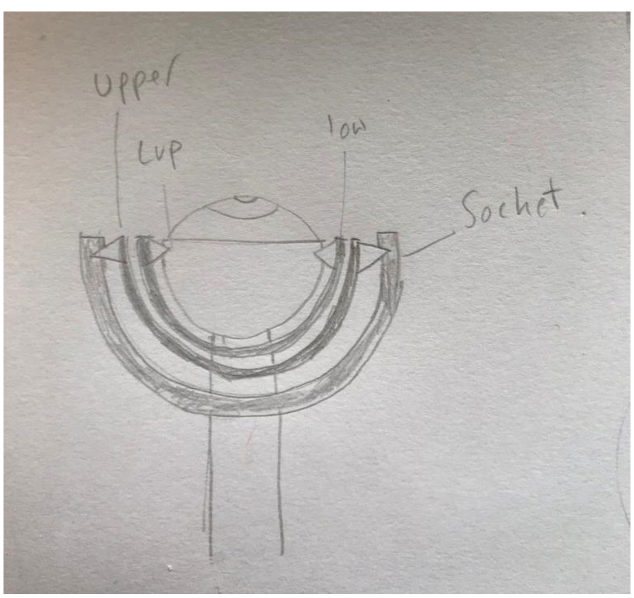
Once printed there were three main issues raised. Firstly, the choice of 3D printing technology, FDM, created textural ridges that would require a lot of post-processing—something that would not only take up time but would reduce the accuracy of the print overall. Secondly, the design of the joint proved difficult to construct post-printing, as the lids needed to be bent aggressively to fit over the brackets, leading to breakage. Thirdly, the eyeballs—having nothing to hold them aloft—rolled around freely within the eyelids, which was not ideal.

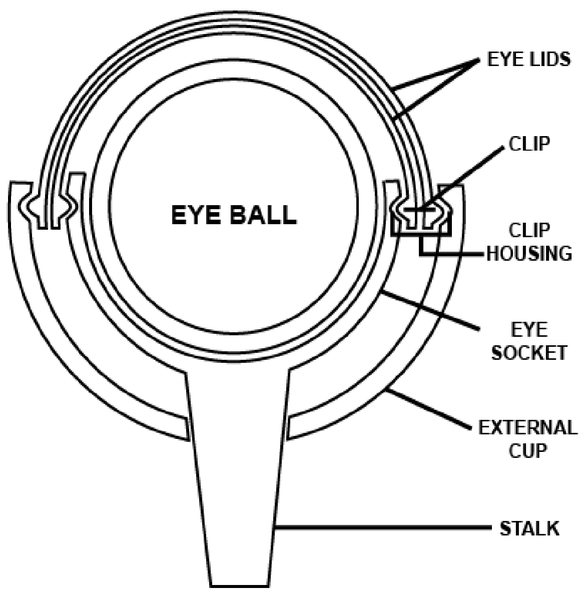
[*Figure 43.* 3D Printed test of second design, FDM printed in PLA. Images used with thanks to Ainslie Henderson.]

At this stage it was decided that I would do the CAD modelling and that we would explore using SLA printing, which would provide more precise parts, with smaller tolerances, as well as a greater variety of materials for enhanced performance.

6.4 Initial Designs by Researcher

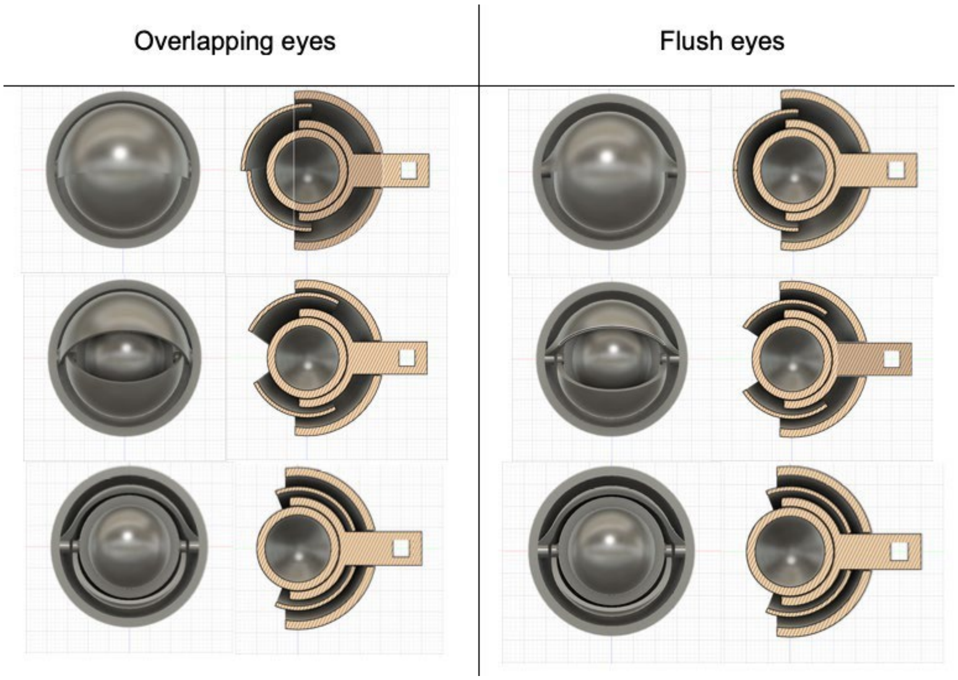
Henderson sketched a new design [Figure 44] that incorporates the eyeball into a socket and cup system, with sliding lids that sit within the gap. The socket would hold the eyeball in place and the cup would protect the eyelids from any outside materials or interference. The eyelids would be held in place with the use of clips housed in either the internal socket or external cup. A naming convention was set in place in order to discuss the design going forward [Figure 45].





[*Figure 44* Left: Ainslie's Initial Sketch for the new design. Image used with thanks to Ainslie Henderson. *Figure 45* Right: Illustration of design with naming conventions]

A stalk was added to the back of the internal socket that slid through a hole created in the eternal cup to hold the internal mechanism in place and in the correct position. At this point, the researcher created an initial design, at which stage a further requirement was raised by the artist to incorporate a set of slitted overlapping eyelids into the system. Two alternative designs were created [Figure 46].



[*Figure 46.* Initial designs by the researcher of overlapping and flush eyes]

6.4.1 Initial Print Test Results


[*Figure 47.* Test prints of 20mm eye system in grey resin Formlab 3. Images used with thanks to Fabio D'Agnano.]

Initial material tests, using the CFPR's Formlabs Form 3 SLA printer in grey resin, were created to address any tolerance changes between the digital design and physical parts.[83] These tests were discussed over video call and then sent on to Henderson for review. While the print quality was determined to be good, minor changes to the overall design were needed, such as changes to tolerances of the stalk, a bevel added to clips to create a tighter fit and to stop the eyelids drooping, as well as a lengthening of the lids to avoid them sliding too far into the cup, which may have made it difficult for the animator to manipulate once constructed. As there was no character design, everything was developed around the size of the eyeballs, which were set at 20mm, 15mm and 10mm. The tolerance of the eyeball within the cup itself was importance as they needed to sit securely but also allow some space for post-processing, such as adding varnish to give a wet-looking surface to the eyeballs.[84]

6.5 Revised and Final Designs

Iterative designs were created, with ongoing feedback from Henderson. One of the earliest considerations was the need for both sets of clips and clip housing to remain central in the design. As everything was rotating around a perfect sphere, the lids had to glide easily over the cup and eyeball and come to meet once closed. This required the creation of very tight tolerances between the overlapping clips. Due to the minor imperfection in printing technology, a guide tolerance of 0.1–0.5mm (Armstrong, 2020) was recommended depending on the amount of movement required between each part. Tolerances between the moving parts were kept to a minimum, to reduce any visible gap between the eyelids and eyeballs, so the internal elements were less visible in the final film, and to reduce the size of the eyes overall. This had to be done in tandem with the functionality of the piece as well as maintaining that the parts would survive the printing process. The artist's desire to continually reduce the tolerances and thickness of parts was discussed openly, and potential issues regarding strength were raised by the researcher throughout. Iterative cycles of tolerance and layer thickness were trialled to reach a satisfactory result.

An initial design was created to incorporate both sets of eyelids into one system at the largest (20mm) scale [Figure 48]. It was later decided that in order to bring the overall scales of the

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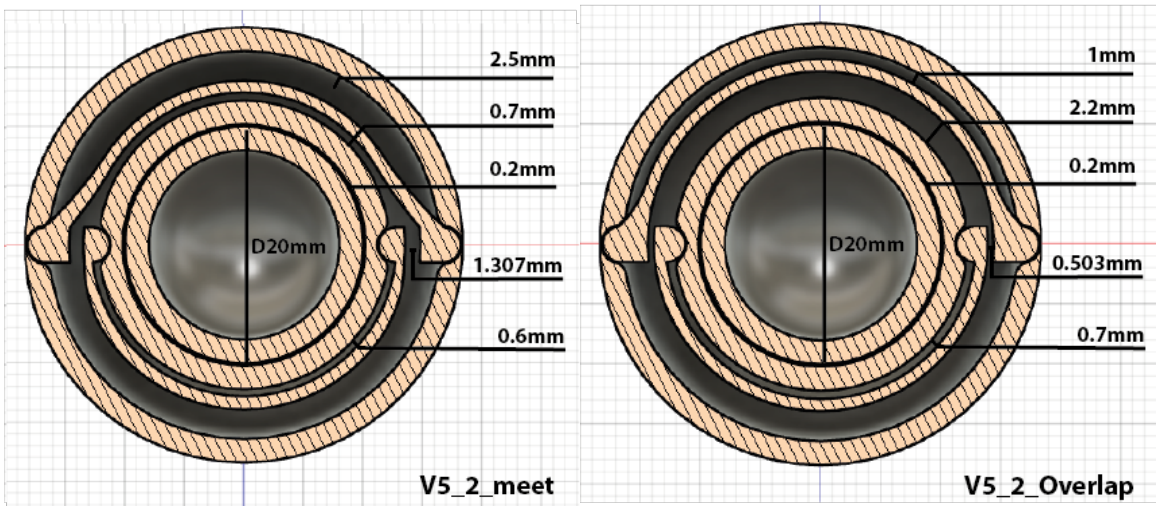
[83] Although SLA printing offers good quality results once printed, there is always the possibility for organic flaws to occur during the printing and curing process—especially when working with extremely tight tolerance, as with this design.

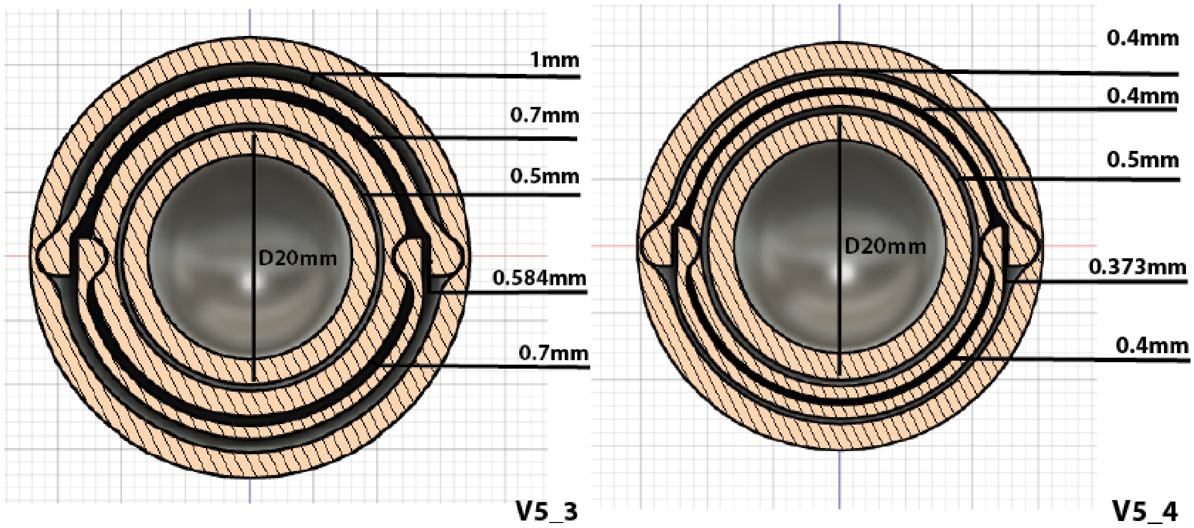
[84] There was also some consideration given to the possible need for lubrication, which ended up not being necessary.

individual eye system down, both sets of eyelids would only be incorporated into the smallest of the eyes, as this was the size most likely to be employed for the IT character (meaning the size of the largest set could be reduced).

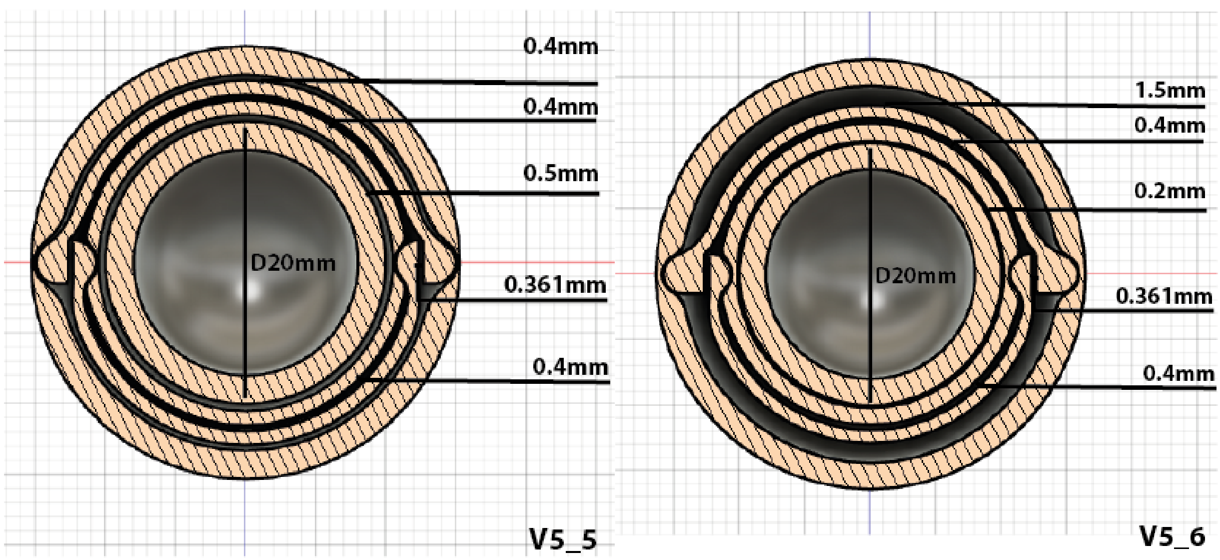


[*Figure 48.* Version 2: Largest scale eye combining both eyelid types. Cup = 2mm Socket = 2mm]

Versions 3, 4, and 5 (seen in Figures 49, 50, and 51) show the iterative design stages that were taken to reduce the tolerance and thus the overall scale of the individual eyes. Changes to the thickness of the socket and outer cup were also made to strengthen the overall design. The lids were kept at a width of 1mm across all designs as this was found to be the minimum achievable thickness.

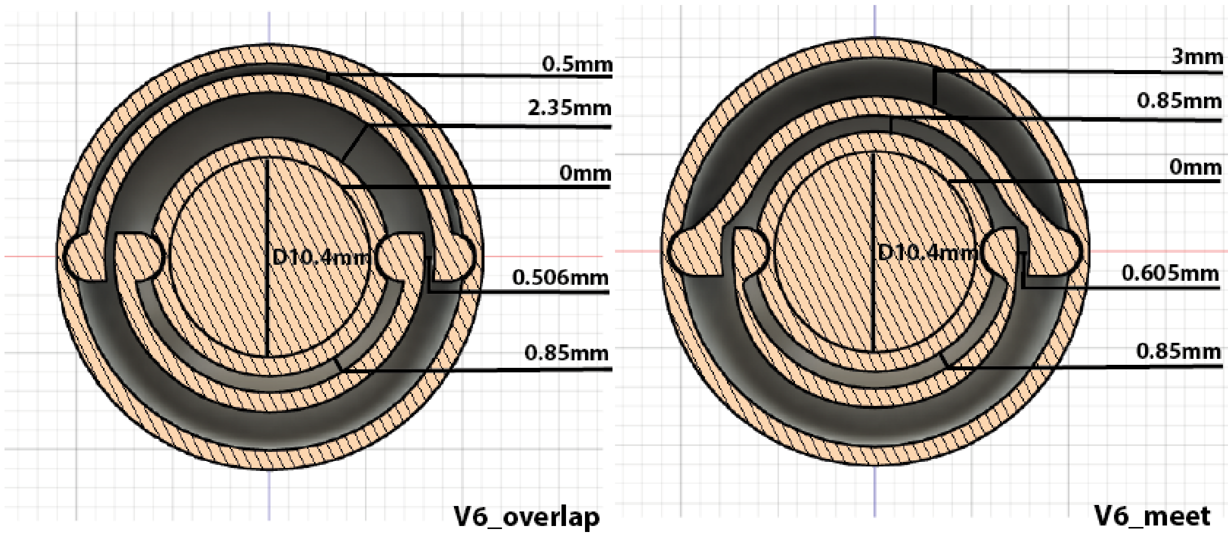


[*Figure 49 (left).* Version 5_3: Cup = 2mm, Socket = 2mm. *Figure 50 (right).* Version 5_4: Cup = 2mm, Socket = 1mm]



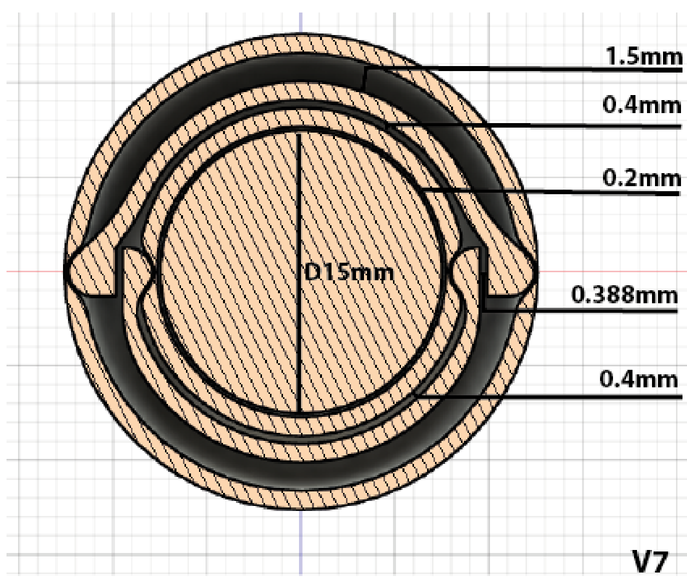
[*Figure 51 (left).* Version 5_5: Cup = 2mm, Socket = 1mm. *Figure 52 (right).* Version 5_6: Cup = 2mm, Socket = 1.3mm.]

Version 6 [Figure 52] represents the final concluded design for the largest scale of the eye. A larger space was needed between the lids and outer cup to stop them sticking, allowing them to glide smoothly in and out of the cup. The tolerance between the eyeball, socket and lids was kept to a minimum and the thickness of the cup and the socket was increased slightly to stop holes forming in the clip housing. The medium scale, based on a 15mm diameter eyeball, and the small scale, based on a 10mm diameter were developed next.



[*Figure 53 (left).* Version 6_overlap: Cup = 1mm, Socket = 1mm. *Figure 54 (right).* Version 6_meet: Cup = 1mm, Socket = 1mm]

Two configurations of the small (10mm) eye were created to incorporate both types of eyelids [Figures 53 and 54]. The tolerance between eyeball and socket was reduced to 0 as it was decided to print the socket in elastic resin to decrease the overall eye scale as much as possible. The eyeball diameter was also increased to 10.4mm, to create a tighter fit.

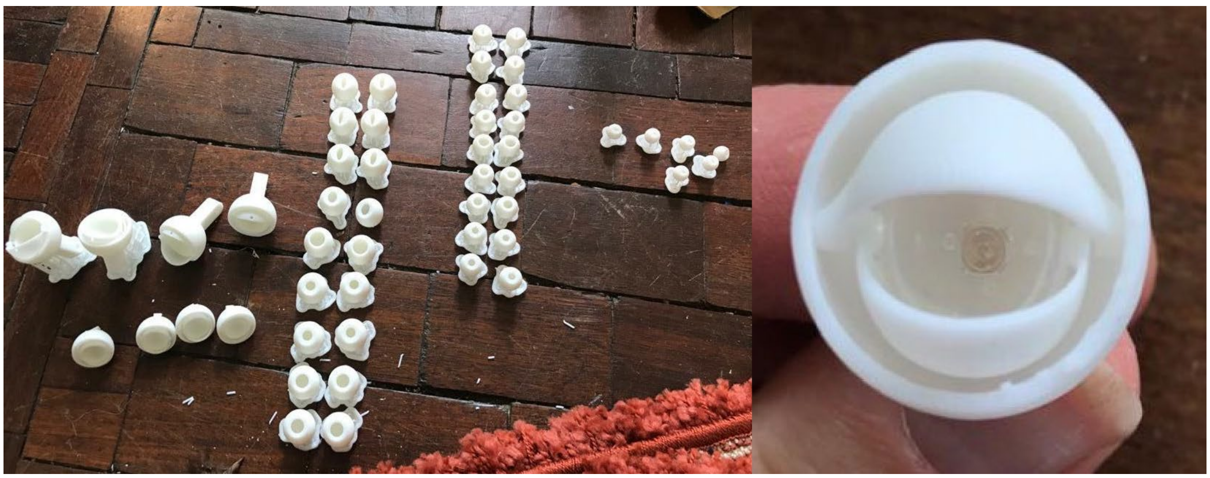


[*Figure 55.* Version 7: Cup = 1mm, Socket = 1mm]

The medium sized eye [Figure 55], was created as a variable scale and only required one set of flush eyelids. Once final designs had been agreed upon, further testing was conducted, at which stage all parts performed well. Final designs were sent to a bureau service to be printed in their selected materials.

6.6 Final Prints

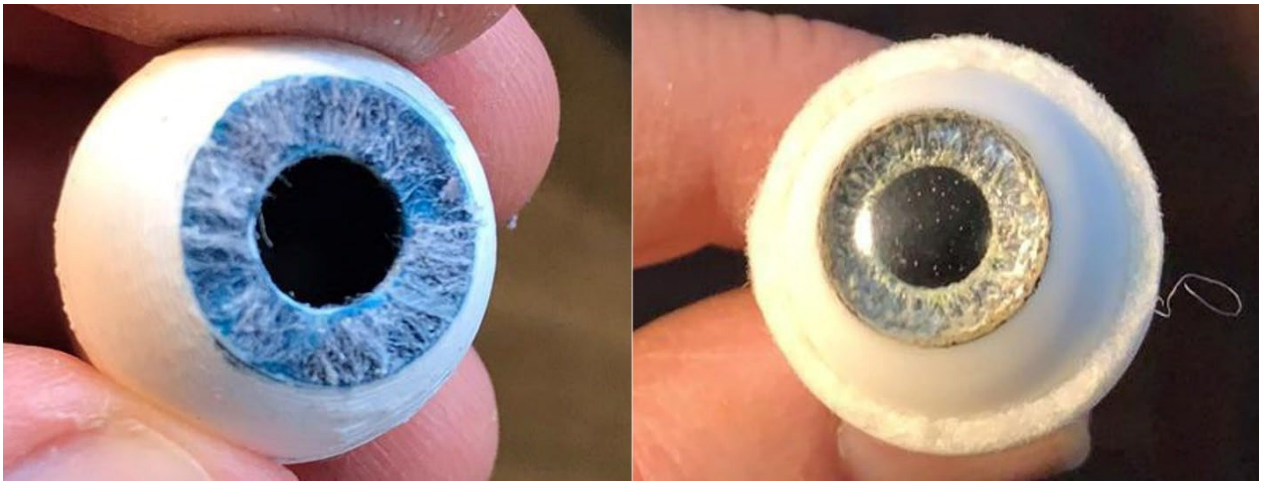
The socket for the smallest iteration of the design (version 6) were printed in Formlabs' elastic resin [Figure 56.2]. All other parts were printed in standard white resin as only the eyeballs needed to fit a specific colour profile. Keeping primarily to one material was more cost effective, as entire printer beds could be filled, reducing additional set up fees.



[*Figure 56.1.* Left: Printed piece for all sets. *Figure 56.2.* Right: Constructed 10.4mm eye with white and elastic resin. Images used with thanks to Ainslie Henderson.]

6.7 Participants' Authorial Aesthetic Results

Once printed, Henderson began to apply his signature authorial aesthetic to the pieces. After initially sanding to remove erroneous artefacts left by support materials, experimentation led him to incorporate paint, resin as well as natural fibres and materials to the manufactured pieces. By painting the inside of the pupils black, using wool to create iris texture, filling with resin creating a dome over the eyeball [Figure 57], then applying a couple of thin layers of lacquer, he was able to create beautiful, mesmeric eyes with depth and craft built into them.



[*Figure 57.* Left – eye detail. Right - with doming clear resin. Images used with thanks to Ainslie Henderson.]

[*Figure 58.* Final eyes created for IT character. Created using coils of wool glued to 3D printed eyelids. Images used with thanks to Ainslie Henderson.]

A concerted effort was made to hide all 3D printed parts, to avoid them showing up on the screen or catching the light and creating unwanted glare when shooting. A mix of techniques were employed to cover the eyelids; Figure 58 above shows coils of wool that were twisted with glue and burnt slightly before being affixed to the eyelids to create a ridged, textured appearance. Figure 60 below shows feathers attached to the eyelids for the character of SHE for a softer, more angelic appearance, further separating the visual look of each puppet.


[*Figure 59. Left* - Base layer for HE character. *Figure 60.* Right - eye system with feathers for SHE character. Images used with thanks to Ainslie Henderson.]

Once a successful system of painting and detailing the eye was determined, Henderson began setting them into the head [Figure 61] and constructing the rest of the puppet around them. To do so, a combination of wood, wool, felt, feathers, glue, resin and other more organic materials were used, creating a range of puppets that sit together as a group but have strikingly different profiles and characteristics.

[*Figure 61* Left - internal head core with eyes for IT. Right - completed IT Character. Images used with thanks to Ainslie Henderson.]

6.8 Conclusion

Once the study was complete, an interview was conducted with Henderson to ask questions about the collaborative process, the outcome of the study, and what the experience has added to his practice moving forward.

[*Figure 62.* Final fabricated puppets for SHACKLE, from right to left IT, HE and SHE. Images used with thanks to Ainslie Henderson.]

During the interview, areas for further development were discussed. Henderson conceded retrospectively that there were some issues with reducing the thickness of parts, as some breakages had occurred since the study was completed (predominantly around the eyelids and the clips). Henderson's desire to reduce the scale of parts—and its effect on the overall strength of the piece—was discussed throughout the study. Ultimately, visual finesse was prioritised over strength; this could be rectified by using stronger resins or with minor alterations to the eye system for future use.[85] However, with spares and extra care, once additional materials were added the overall strength was increased and became stable.

Henderson also noted the complexity of the post-print construction of the eyes, especially once additional materials had been added, and that he found it difficult to put it together inside the external socket once housed in a puppet. Although awkward, this was largely a compromise made for the overall style of the puppets' fabrication; an external socket was needed to avoid other external material used in the construction of the puppets potentially interfering or compromising the internal mechanism of the eye.

[85] Tough, Durable and Rigid resins, developed for stronger mechanical parts, offered by Formlabs (as discussed in chapter 4) could be used to address the issue of breakages in the extremely small, thin pieces such as the eyelids and clips. This would, however, have a knock-on effect on the overall cost as more robust resins are more expensive.

[*Figure 63.* Squinting eyes of HE character, used for subtle movement within the scene. Image used with thanks to Ainslie Henderson.]

The study was successful in providing the filmmaker with a bespoke eye mechanism system for both this current project and future projects. The eye mechanisms are customisable whilst remaining structurally and mechanically functional. The eyeballs were hollow and allowed for internal painting to create depth. The combining of traditional and digital craft has in effect allowed for a greater level of detail and complexity for the filmmaker whilst also providing a future way of working that may give his films a greater authorial fingerprint[86]:

> I have a set of eyes that are going to work better than any eyes I have used in the past. Particularly the eyelids, the way that they can close and open and emote. [...] They'll be more effective than anything I've had in the past.[87]

Early tests and excerpts from the film show that the eye systems were successfully housed in three entirely different puppets that were able to sit together on screen and inhabit the same world whilst offering different expressions and performances for each character, largely through their eyes and gestural movements. The movements afforded by this system are highly precise

[86] Since the conclusion of the study Henderson has developed a series of GIFs for sale, via NFTs, entitled *Beautiful Rowdy Prisoners.* The eye system has been used for multiple puppets that come together to form a band that use everyday objects, such as paper, to make music. This demonstrates that the artist has been able to take the eye system forward into future work and create a signature element through all his puppets.

[87] Interview with Ainslie Henderson, personal communication, 19th October 2020. Full transcript found in Appendix B.3.

and impactful. The system has allowed new levels of subtlety whilst also remaining simple for shooting in their live action setting.

[*Figure 64.* In-shot replacement of eyes for SHE character . Images used with thanks to Ainslie Henderson.]

Different eyeballs were created to allow for in-shot replacement to benefit the narrative and visual motif of the characters as their animalistic desires take over. This can be seen throughout the film [Figures 64 and 65]. This replacement technique allows for subtle but impactful changes in both the look and demeanour of the characters, as expressed through the animation performance.[88]

[*Figure 65.* Left - Close up of in-shot rounded iris eyes of SHE. Right - Reptilian eyes of SHE. Images used with thanks to Ainslie Henderson.]

The eye mechanism has allowed for a consistent but fully customisable base for the artist to use both on this project and in future work. Due to his involvement and feedback at every stage of

[88] Video clips and excerpts from the film in development can be found in the accompanying materials folder included with this thesis (“Chapter6_SHACKLE_VideoClips”).

the design, his authority over the process has not been lost and has resulted in a mechanism he both understands and feels complete ownership over, sufficiently demystifying the 3D modelling and printing process. By involving the filmmaker in every aspect of the process the study has provided new knowledge and new ways of working to the filmmaker whilst retaining his authority over the outputs.

This case study has uncovered a wealth of new possibilities for filmmakers through the use of 3D printing. Within the overall aims of this thesis, this case study has produced evidence of 3D printing being used as a tool for auteur filmmaking; the technology has proved effective in increasing the authorial and technical potential for future filmmakers. Once the initial hurdle of technical skill has been rectified, either through training or liaising with a facilitator such as the researcher, further novel uses can be found to benefit more auteur productions. The case study has identified strengths and weaknesses of 3D printing visually and mechanically through the iterative cycles of practice in the development of physical artefacts. This has facilitated the discussion with the practitioner regarding craft skills, authorship and the aesthetic potential when using 3D printing for puppet construction.

Chapter 7. Aesthetic Potential of 3D Printed Animation

We have so far established that the potential for 3D printing within animation is not necessarily in the cost or speed but in uniquely creative approaches to both large and auteur productions. At this stage in animation's history, we are no longer beholden purely to how or why something should be animated. The exploratory nature of animation has always been part of its development and a much-celebrated aspect of its creation. In this chapter, I will discuss the ways that 3D printing creates different aesthetic outcomes, using prominent examples to represent various considerations that may affect future use of 3D printing.

7.1 Aesthetic Attention and Design Appreciation

In 2018 I presented a paper[89] raising considerations and concerns about the current uses of 3D printing in industry, much of which laid the foundation for this thesis. In the subsequent Q&A I was asked why filmmakers choose to make work that uses hundreds of thousands of replacement faceplates. Since then, similar questions have been asked by students, critics, and colleagues, either through papers or articles, to filmmakers or myself, and one I have continuously tried to answer throughout my entire thesis and investigation. I often refer to one of the earliest interviews I read on the subject in which LAIKA CEO/Director Travis Knight said "Technology isn't about making the job easier or faster. Primarily it's about achieving a specific aesthetic you can't get any other way" (Alger, 2012:48). This simple statement has been a guiding truth throughout this study.

As eminent academic Maureen Furniss states in her book *Art in Motion*, "animation falls in the intersection of many artistic practices" (1998:61). This, in part, is what makes animation aesthetics a particularly difficult subject to pin down. Philosopher Noël Carroll describes aesthetics—although closely linked to the idea of beauty and distinguishing between good and bad art—as primarily about understanding or appreciating a film, object, or anything that otherwise enriches our personal or collective experience of life. At its most simple it can be understood as a set of considerations, developed by artists to give us "aesthetic experiences" that we can attend to or read in various ways (Carroll, 1999:159–61). Carroll highlights the concept of the "affect-oriented" account, which he defines by its "disinterested and sympathetic attention" as well as "contemplation of any object" (170). This refers not to a lack of interest but

[89] "The changing face of replacement animation: how looking to the past can revolutionize the future of stop motion animation" (*The Society for Animation Studies Annual Conference: Then | Now | Next, Concordia University, Montreal, 19.06.2018*).

"interest without ulterior purposes […] to judge the case [or artwork] impartially and on its own merits, rather than on the basis of issues and purposes external to [it]", by attending to an artwork disinterestedly, "we can appreciate it for its own sake, not for its connection with practical issues" (170–71). In this way, 3D printing is understandable as an aesthetic choice less concerned with money, time, or practicalities and more with expectations of aesthetic experiences outside of the parameters of profit or sociological concerns. The rationale behind these technological developments is to pursue the new, the novel, or the 'perfect'; whether this has been achieved is debatable, but the pursuit lies faithfully in the minds and hands of the maker.

In attending to an artwork disinterestedly we also attend to it sympathetically, "playing by the object's own rules, rather than importing our own" by putting ourselves in the "hands of the maker" (Carroll, 1999:171). Sympathetic attention can be attributed to the world-building and rulemaking often developed in the creation of new animated works. David O'Reilly (2009) refers to this as "coherence", not as a way of "following specific ideas" such as appeal, but of keeping elements of a built world "consistent". These rules are applied in his work, to create distance from the distracting influence of CG animation in which he suggests there is "too much power and very little control"—the allure of CG animation in which anything is possible, and our collective perception of realism contributes to ever-increasing expectations of animation technology, resulting in exponentially diminishing returns. However, these freedoms should not be diminished; as O'Reilly states, "there is so much possibility in 3D software to create original worlds there is simply no excuse to try and recreate other ones" (O'Reilly, 2009). These rules can be attributed to a content-oriented account of aesthetic experience examining the properties of a work, defined by Carroll as "unity", "diversity" and "intensity". Rulemaking can be seen as unity in which "elements of the work are coordinated in part or throughout" thus "unified" through "motifs" or "themes", into one "coherent effect" (1999:168).

However, with disinterested attention comes the idea that a less open-ended or intentional focus of analysis makes such attention less or somehow un-aesthetic (184–89), which is both an unsatisfactory definition and, of course, false.[90] Addressing this, Carroll usefully suggests

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[90] Of course, not all artwork fits within the remit of aesthetic experience; as Carroll points out, anti-aesthetic art has had a long and fruitful history. Although these aesthetics concepts may not apply to all artwork, they are useful when discussing the specificity of aesthetic experience as innately human experience. A willingness to explore work from a disinterested, contemplative, or sympathetic position allows us a certain level of unbiased "openness" to experiences (181–84). I would not consider myself an advocate of Charlie Kaufman's work, but I can appreciate the aesthetic experience of his films through a

“design appreciation” not as a “special kind of attention” but as an alternative or additional way of “focussing attention” limited “to the form of the work” (189). Carroll distinguishes properties such as “weight, mass or length” as base properties that can be calculated or “quantitative” from aesthetic properties that are largely “qualitative”, being psychologically or emotionally “response-dependent”. Although these properties all exist in the same physical and conceptual space, aesthetic properties are often harder to articulate but nonetheless exist and are important in our understanding of all things (190). Two people seeing the same object can read its properties subjectively, but these differences can be attributed to “personal preference” or “differences in categorization”; the convergence of opinion, however, can lead to an objective reading of the same object (198–200). The enduring charm of stop-motion is often referenced in its use of tangible, physical materials that incorporate and highlight the hand of the maker. By addressing the aesthetic properties within this form, we can appreciate not only the works themselves but also our own experience of them.

7.2 Remediation and Fetishization

Remediation, as defined by Bolter and Grusin, is “the formal logic by which new media refashioned prior media forms” (1999:273), understood through the dual strategies of immediacy and hypermediacy. Immediacy “dictates that the medium itself should disappear and leave us in the presence of the thing represented” (5–6). It is a “style of visual representation” that aims to “make the viewer forget the presence of the medium […] and believe that he is in the presence of the object of representation”, whilst hypermediacy’s “goal is to remind the viewer of the medium” (272–73). In this way, 3D printing can perceivably create a more immediate experience for the viewer of the stop-motion work, by creating more fluid motion and removing as much of the staccato movement associated with early stop-motion works as possible. Although audiences are under no illusion that characters are not animated, it becomes increasingly difficult to differentiate between animated forms. However, immediacy is reliant on the hypermediated awareness of the medium itself. There are two logics to the social dimension of remediation as described by Bolter and Grusin; firstly, immediacy can be understood in an “epistemological” sense as “transparent”, through “the absence of mediation or representation”, or a “physiological” sense, wherein audiences perceive that the medium has “disappeared” and

willingness to engage through a combination of sympathetic and disinterested aesthetic attention (as seen later in this chapter). As Carroll acknowledges, “aesthetic experience is something we pursue for its own sake” (Carroll, 1999:172).

is thus considered more “authentic”. Secondly, epistemologically, hypermediacy is opaque, in that the audience is aware and acknowledges the medium in use. Physiologically, hypermediacy allows the audience or viewer to experience the medium as an “experience of the real” which also creates a greater sense of “authenticity” and bridges the two logics together (70–71):

> If the median really disappeared, as is the apparent goal of the logic of transparency, the viewer would not be amazed because she would not know of the medium's presence. […] The amazement comes only the moment after when the viewer understands that she has been fooled. This amazement requires hypermediacy, and so the double logic of remediation is complete. (Bolter and Grusin, 1999:158)

In discussing the illusionary effect of cinema, Bolter and Grusin describe how audiences have “a recurring fascination with the medium […] the viewer oscillates between a desire for immediacy and a fascination with the medium” (82). Viewers may seek “transparency” or immersion into a film yet remain fascinated with the fabricated world they temporally occupy, thus retaining the presence of hypermediacy despite the ever-developing technologies that seek to remove it; in other words, “transparency needs hypermediacy” (84). Although commercial animation is foremost about entertaining and telling interesting stories, many stop-motion films—particularly those of LAIKA—routinely use behind-the-scenes footage to reveal the process, drawing the audience out of their immediacy and into a hypermediated state.[91] These fabricated materials could be fetishizing craft, as Glenn Adamson acknowledges regarding the pastoral engagement with craft as a process for its own sake through the “camera’s lens” (2014:110–14). In reference to a talk by Alan Warburton wherein he notes the “fetishized analogue practice” demonstrated in the 2013 commercial *The Bear and the Hare* (Warburton, 2016:02:22), Brigitte Hosea (2019) cites how the project “works hard to look handmade, but is actually primarily digital”. By using laser-cut characters, animated by hand, “the laborious and painstaking nature of production becomes part of the marketing strategy” (Hosea, 2019:33). Hosea later directs this at LAIKA’s use of behind-the-scenes footage to advertise their films, as well as the 3D printed replacement system they are largely known for:

[91] However, this relies heavily on the assumption that the audience seeks out these adverts or stay throughout the credits at the end of the film. LAIKA certainly does not hide the perceived value of new technology in combination with traditional techniques, moving further and further into a more remediated state, making full use of the technology at their disposal. Shadbolt concurs: “It is as if the filmmakers want to remind us that making something look effortless requires an almost superhuman amount of effort” (Shadbolt, 2021:13).

> Their hybrid process involves a sophisticated library of replacement parts that are created by CGI modelling and then 3D printed for hand manipulation on set. It is hard to understand why the manual stop motion process was necessary at all beyond a fetishization of virtuoso craft and labour-intensive processes. The film could just as well have been CGI animation as the result is so perfect that it no longer looks handmade. By the time the rigs and armatures have been digitally removed, the textures become so smoothed out that, to all intents and purposes, it looks synthetically produced rather than handmade. […] craft as a method of production is foregrounded in the marketing material for the purpose of spectacularising the labour, while the resulting aesthetic looks digital. All that effort was unnecessary and digital tools could have been used for an identical result. (Hosea, 2019:33)

Although it is true that many of the materials are used to advertise and elicit excitement for their work, it is also done to educate and inform the viewers on the process and negate the possibility of people misinterpreting the animation processes used in the film. Although Hosea's opinion is valid and certainly echoed by other scholars (Cook, 2021:32; Harris, 2021:51,55; Owen, 2021:135; Shadbolt, 2021:125; Torre, 2021:104),[92] and critics (Sancton, 2009; Robinson, 2016; Amidi, 2019), the unique aesthetic qualities of 3D printing, that would not be otherwise possible, remain unrecognised.[93].

7.3 Animation Realism Aesthetic

Animation aesthetics, in their broader sense, contain conventions and intrinsic functions, not only in concurrence with—and in opposition to—the classic Hollywood live-action system and mainstream commercial animation, but also in avant-garde or experimental modes of production. As Paul Wells (1998) acknowledges, to animate means to "give life", and within animation "this largely means the artificial creation of the illusion of movement of inanimate lines and forms" (10). This "illusion of life", although not universally applicable, continues to pervade animation studies (Husbands & Ruddell, 2019:8). Wells further notes that realism is a relative term in animation; the idea of "hyper-realism", as related to Disney, can be understood as the way in which "characters, objects and environments" are subject to conventional "real world" physical laws (1998:25). Walt Disney advocated "action analyses" to his animators to improve

[92] Miriam Harris (2021), in discussion with LAIKA armaturist Emily Myers, notes how "innovation for the sake of innovation" can sometimes overshadow the functionality of puppets and time restraints within the departments. Harris suggests a level of "soul-searching" for LAIKA (55), warning against the potential that through their pursuit for "digital spectacle" they may inadvertently create work that closely mirrors the work they seek to "differentiate themselves" from, namely CGI (51).
[93] A more focused discussion of LAIKA's use of 3D printing, can be found in section 7.3.1.

their understanding of the “mechanics of real-life and animated movements” (Furniss, 1998:79). Disney wanted animated characters “to move like real figures and be informed by plausible movements” (Wells,1998:23). Due to Disney’s dominance over the industry to this day, the concept of “realism” or “hyper-realism” (105) remains a prominent feature of all animation practice and study (24). As Michaela Mihailova (2019) reiterates, Disney was “careful to incorporate reasons for any anti-realistic appearances or behaviour of its character into the film storyline legitimising aesthetic expectations via conventional narrative” which “set the tone for contemporary animated features, which favour convincing appearance, movement and behaviour” (52–53)

Realism is not the only consideration in animated works, but it has become a prominent focus for many features and larger studios. As technology has developed, animators have developed various techniques to pursue the real; as Lev Manovich (1197) acknowledges “each new technological development […] points to the viewers just how unrealistic the previous image was and also reminds them that the present image, even though more realistic, will be superseded in future”.[94] With new tools comes the potential to reach new levels of realism, photorealism, or perfect mimetic representation (7–12). As Mihailova (2019) discusses, these tools offer an “enhanced version of the same illusion of movement” as was established within “cartoon realism” (2019:52). Rather than reading the ‘illusion of life’ or ‘hyper-realism’ as a desire for photorealism, it is more reasonable to equate these illusions with magic. Once a magician performs a trick, we generally do not go on to believe magic exists tangibly in our world, nor is that the purpose of this act of entertainment. As with animation, in the moment of ‘illusion’ we lose ourselves in a moment of suspended disbelief, in order to engage with the cinematic work. Stop-motion offers a unique additional sensation as it already sits within the same world as the audience[95]; something Mihailova (2019) also recognises as a “more immediate and direct” phenomenon, which she relates to the work of LAIKA, who “strike a

[94] Manovich also highlights how the development of technology that aimed to simulate “visual reality” was partially due to the financial supporters of the technology—such as the military, government, and Hollywood—as well as computer graphic researchers themselves who were also keen to develop realism towards the “mastery of mimetic representation” (11–12). This in turn could be seen as a drive towards photorealism. “Photo-realistic computer graphics”, as described by Bolter and Grusin, “seek to create a space that is purified of all reference to itself as a medium and to other media” (1999:115). Computer graphics experts often strive for “photorealism” and making “synthetic image[s] indistinguishable from photographs”; this is equivalent to a “computer animation” desire for “filmic realism” in which an animated sequence would be indistinguishable from “traditional film” (28).

[95] As Furniss highlights, stop-motion characters “have inherent surface texture and are subject to the laws of gravity, but variations in terms of movement and the display of emotion can occur when different types of puppets […] are used” (1998:163).

balance between caricaturing and emulating reality […] not unlike the classic Disney approach" (49)—a quality that we will explore in the next section.

7.3.1 Limitless Perfection

LAIKA has developed a reputation for incorporating cutting-edge technology into all areas of production to increase levels of nuance, realism, hybridity, and perfection. As Malcolm Cook (2021) explains, *Coraline* (2009) represented "a historical moment in which the visible materiality of stop motion was understood to relieve the clinical flawlessness of computer-generated imagery" (27–28). Although LAIKA's films vary widely in both narrative and visual design, what unifies their work are the qualities derived from mixed-media or 'hybrid' approaches to filmmaking. Miriam Harris notes this hybridity is created through combining "disparate stylistic sources" as well as "analogue and digital techniques" (Harris, 2021:41). The 3D printed replacements in particular lend their films a specific visual tell. Along with their ability to fabricate extensive new worlds for each film, LAIKA's calling card has become a drive towards greater cinematic wonder through complex, practical and digital effects, over a more customary focus on recurring characters, specific genre, or reliance on broad, slapstick humour. As Travis Knight explains:

> [At] Laika, we're a fusion of old and new. We hold reverence for tradition mixed with fervour for innovation. We work in a medium that's over a century old, but we bring a passion for cutting-edge technology and avant-garde creative approaches. We are cavemen and astronauts. Luddites who have embraced the loom. (Watercutter, 2015)

In conversation with Brian McLean, when asked how he felt the application of these technologies continues to affect the aesthetic of stop-motion animation, he stated that:

> One of my main responsibilities is to leverage technology to eliminate limitations. To find ways and define new workflows or discover new technology that's going to give the director exactly what they want in terms of performance and look. So I'm always striving for perfection in technology because I don't want to say to a director "I'm sorry, you can't do that", or "We can't do that because of some limitation". As a creative leader with the studio it is a terrible feeling of having to say no to a director. I'm always searching for technology, computer software and techniques that are going to produce a new level of perfection in terms of how a character looks and how it performs. […] We scrutinise

> every frame to make sure that there's no flecks on a face and to make sure what's captured in-camera is as problem-free and perfect as humanly possible.[96]

When asked if the pursuit itself was perfection, McLean added:

> We're constantly going back and looking at our previous films […] performances […] puppet builds and finding […] things that we just weren't happy with in the moment and asking ourselves "How do we fix that?" Everyone that works at LAIKA is always striving for perfection. […] Really it's not a drive for perfection to make something look a certain way, it's a drive for perfection that we just want to be as proud of as we can be.[97]

This can be seen throughout LAIKA, from the minute detail in their costumes, to the high-end VFX used throughout their films. A continuous strive for nuance has led the LAIKA team away from their tried and tested library system—which has increased in complexity with each project—to completely "bespoke facial animation" in their most recent film *Missing Link* (2019), as director Chris Butler explains:

> The facial animation in previous movies was a library system, […] That's worked great for us, but I wanted greater subtlety of performance to match the subtlety of performance that we've obtained with the puppets. So, every shot in this movie is bespoke facial animation, there's no kit system, every shot was animated specific to that shot so every face is specific to a certain line of dialogue, it's never re-used (or very few are re-used). That allowed for a level of nuance and sophistication that we've always wanted but never had before. (Cowley, 2019a)

Butler emphasises this is not done for technological spectacle, but to enable audiences to be "compelled by the story and the characters", pulling various processes together the studio is able to make their films unique (Cowley, 2019a). An in-depth article by Sam Davies of TCT magazine[98] details various procedural and technological changes within LAIKA. On *Coraline* (2009), more than 200,000 faces were produced with the Eden 260 PolyJet machines, using the solid white plastic material available at the time. Each face was hand sanded, primed, and painted. To help with accuracy, sunken freckles at 1/3,000" deep were incorporated onto Coraline's face, allowing paint to sit just below the surface (Davies, 2018). *ParaNorman* (2012)

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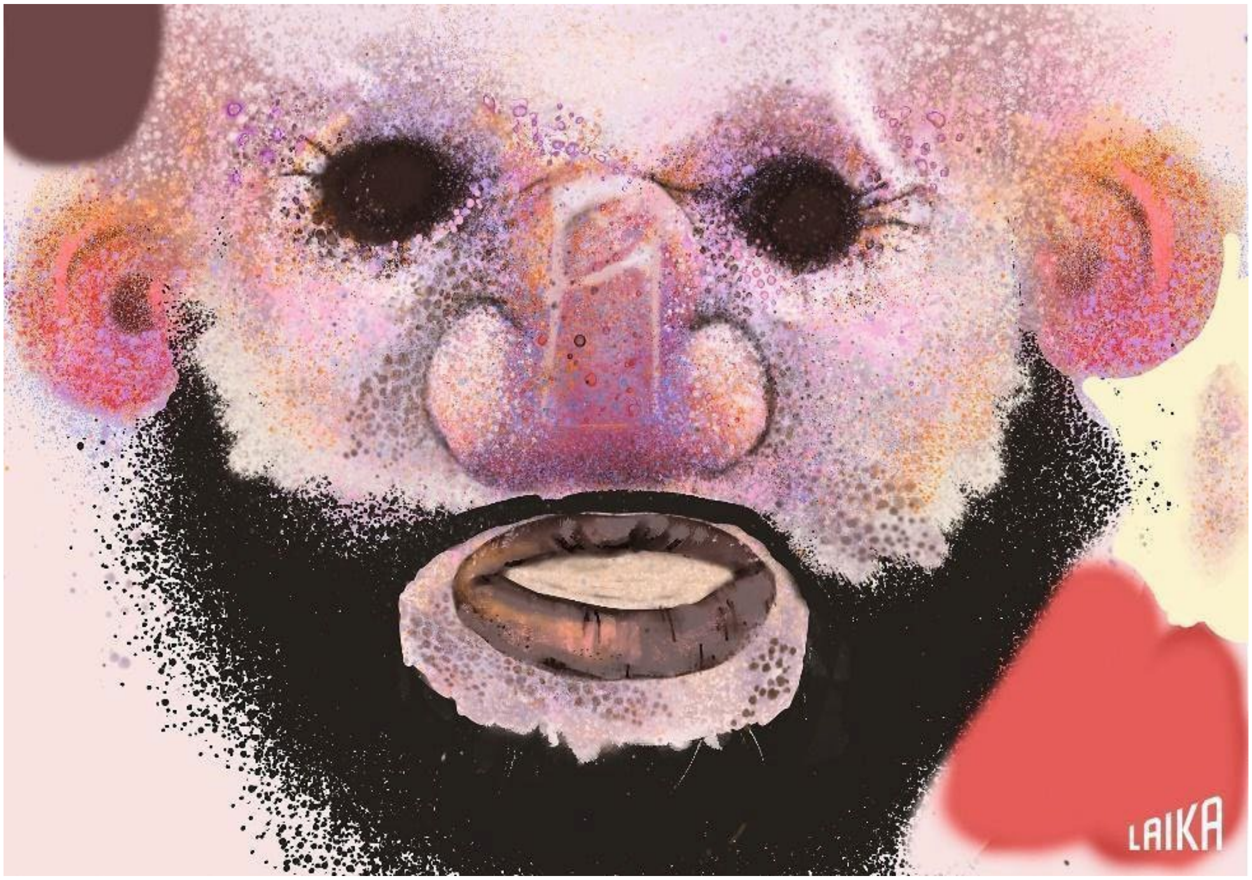
96 Interview with Brian McLean, personal communication, 6th April 2020
97 Interview with Brian McLean, personal communication, 6th April 2020
98 TCT is the foremost news outlet for 3D printing and additive manufacturing news and also hosts an annual showcase at the NEC in Birmingham of the most cutting-edge technology, distributors and people working in the field, which I attended in 2017.

became the first stop-motion film to use colour 3D printing, using Z Corp[99] Z650 machines with powder-printing technology and colour-printing capabilities, whilst still using the PolyJet system for internal head mechanics (Davies, 2018).[100]

[*Figure 66. ParaNorman* (2012). Image used with Special Thanks to LAIKA Studios]

Powder-printing creates a textured surface finish described as "fluffy" (Hoskins, 2013:126). This "translucent", dappled texture diffuses light as it hits the surface, creating a glow resembling real skin (Alger, 2012:50–52). By creating paint textures in Photoshop and mapping them to the faceplates sent to the printer, they were able to trick the printers into being more "colour literate" than they were intended to be by incorporating "crosshatching" to combine colour in layers (Davies, 2018). The same system was used for *The Boxtrolls* (2014): vibrant, unorthodox colours inspired by expressionist artists such as Otto Dix and Max Pechstein were developed by face-painting supervisor Amy Wulfing and her team and reproduced by Head of Digital Face-Painting Tory Bryant for colour 3D printing (Brotherton, 2014:152).[101] The result was a painterly visual style mimicking the organic flourish of the individual creative. In this way, the fingerprint of the artist has been replicated thousands of times in each replacement face. Control limitations remained, however, resulting in thousands of inaccurate faces being built and printed, with up to 40% discarded (Davies, 2018).

[99] Now 3D Systems.
[100] As discussed in section 3.2.1.
[101] Which, at the time, still presented a challenge regarding matching the colours on the screen to what was possible through the machines. To get around this issue, Bryant analysed the originally painted maquette and the printed heads under real stage lights and manually altered the digital file accordingly, to "trick" the computer into creating the desired outcome (Brotherton, 2014:152).



[*Figure 67.* Painted face texture. Image used with Special Thanks to LAIKA Studios]

As they pursued even finer detail in the character designs for *Kubo and the Two Strings (2016)* the limitations of the current tech began to show. As McLean outlined, the "technology we had been using for the last four years had hit its ceiling. We had squeezed as much out of it as we could" (Davies, 2018). Having maintained a relationship with Stratasys—who bought out Objet in 2012 and developed the technology further—they were given access to an early beta version of their updated Connex3, which could combine three colours at once. Even though it did not offer the same colour capabilities as the Z650 they had been using, it was far more reliable. Using the AMF file format[102], they were able to control each droplet—enabling them to create gradients through "dithering patterns" to produce a library of "custom shade[s]" that effectively "increased the Connex3's colour range, from 46 to 256", giving the team full control of hardware

[102]As discussed in section 3.4.4.

and software for the first time, enabling up to 80% of the faces to be ready straight from the machine (Davies, 2018).[103]

[*Figure 68.* Susan's face detail for *Missing Link* (2019). Image used with Special Thanks to LAIKA Studios]

For *Missing Link* (2019), LAIKA used the Cuttlefish© driver developed by Fraunhofer Institute in combination with an updated Stratasys J750. This allowed for full-colour CMYK spectrum-printing with clear and white resin (Hoskins, 2018:155). LAIKA were able to use this machine three years prior to its release, offering over "500,000 colour combinations […] to print [the] 102,000 faces for the Missing Link" (Davies, 2018). What differentiates the aesthetic quality of colour 3D printing, from hand-painted or back-painted silicone heads, is the unique way the colours are formed, both on and under the surface. In a presentation at the AT&T Developer Program, McLean explains how each object is made up of millions of clear and coloured

[103] Although supports still need to be removed—first by using a bath of sodium hydroxide and then water for an hour each, before drying and applying a clear coat of gloss (Davies, 2018).

voxels[104]—individual dots of colour that do not mix, but instead sit against one another to create new colours, like a microscopic “pointillist painting” (AT&T Developer Program, 2018:22:30). The result is a dithered distribution of colour that continuously blends to create various ombre effects—a unique and otherwise unreproducible visual.

[*Figure 69.* Attention to detail. Image used with Special Thanks to LAIKA Studios]

When it comes to perfection, Richard Sennett underpins that “to the absolutist in every craftsman, each imperfection is a failure; to the practitioner, obsession with perfection seems a prescription for failure” (2008:45–46). In this way, the use of individually printed faces for every frame has created a system of replacement animation akin to “full animation” in which “every [image] in a production is used only once” (Furniss, 1995:135). This can be seen as a return to the metamorphic process of other stop-motion forms, such as Claymation, that require every movement to be sculpted.[105] Live-action footage is often studied in order to create what has

104 Three-dimensional pixels.
105 This does, however, begin to strip away one of the original benefits of replacement in offering a library of interchangeable faces, although this has been continually extended with each new film.

been referred to as “LAIKA’s trademark naturalistic and anatomically correct performances” (Zahed, 2019:72). LAIKA has also started to achieve success in using AI for the removal of the face breaks in the facial plates, as well as potentially for puppet rigs and “other artefacts” using automated masking (Angelini, 2020). At this point, the level of perfection is so high, members of the crew have removed intentional details, believing them to be mistakes, as Director Chris Butler explains:

> There’s a shot where Lionel is listening to Link where his lips part and his lips stick together slightly—that level of subtlety. Weirdly enough when the CG guys got that shot, they cleaned it all off because they thought it was a mistake! I was like, “Put it back, it’s supposed to be there!” (Cowley, 2019a)

As Lilly Husbands (2019) notes on the development of skill in animation, “specialist knowledge” gained through “repetition” and “mastery of technique and technology” within the “commercial realm” is developed principally to achieve “high degrees of mimetic realism” (Husbands, 2019:61). Within CG there is a push towards “mathematic” perfection incurring further cost and labour through adding “imperfections” whilst “genuine glitches [or] defects remain taboo” (Husbands, 2019:65). By incorporating CG into the stop-motion pipeline, studios like LAIKA have been able to pursue the same perfectionist trait that has come to represent CG and the commercial industry as a whole[106] or, as the example above highlights, even intentional details may be removed for fear of flaws. This push towards hyper-realism and perfection may move us away from Disney’s (or, in this case, LAIKA’s) stylised realism to more evocative and potentially unnerving visuals, as discussed in the following section.

7.3.2 The Uncanny Dimension

[106] As Bolter and Grusin suggested back in 1999, a thrust for technological advancement and trust in its ability to progress or offer “salvation” can be seen as a prominent feature of the American idea of progress (1999:61). In this way, “American culture seems to believe in technology in a way that European culture […] may not” (60). As with perfection or hyper-realism, the pursuit of innovative technological breakthroughs is perhaps most obviously exemplified by Disney, through their continued and dominant effect on the entertainment and media industries. It is not surprising that LAIKA has been thought of as mimicking this “visionary” persona, rising quickly through a similar drive for perfection, hyper-realism, and technological advancement of the craft of stop-motion that has often seen them referred to as the studio that “revolutionised stop motion animation” (Kamen, 2014). As Herhuth (2021) pinpoints, the “techno-capitalist ethos that believes the real cure for stop motion’s supposed stagnation is an innovative, well-funded company”— something he notes as being a prominent feature of the “well-funded” studios in which a “commitment to innovation has been driven by corporate investment” that may aim to “downplay its corporate culture” but promotes “technological innovation, occasionally treating past (or less expensive, independent) stop- motion practices as obsolete” (Herhuth, 2021:196).

Although prominent in discussions around CGI, VFX, and games, the uncanny occurs in multiple disciplines including literature, robotics, and psychology. Early writings on the subject by psychologists Ernst Jentsch (1906) and Sigmund Freud (1919) identify the uncanny in various objects and situations that can evoke the sensation, including wax figures, automata and ill or deceased people (Jentsch, 1906:12,15). Eric Herhuth (2021) explains how stop-motion puppets elicit similar uncanny sensations through the "jittery movement or visible wires/seams/ thumbprints" of early films, but also the heightened "uncertainty" stemming from their material "tangibility" (195). Angela Tinwell (2014) describes uncanniness as occurring "when objects or situations evoked a sinister revelation of what is normally concealed from human experience. […] We experience the uncanny when we identify something hideous or unsettling that we or others may have been attempting to hide" (4). The "uncanny valley", a term coined by robotics professor Masahiro Mori (1970), used a graph to show a rise in affinity of human likeness that steeply drops off into a valley once the degree of resemblance moves from identifiably inhuman to more detailed, less-perceptibly, unnatural, humanistic forms. Using a prosthetic hand, Mori explains that once we identify that "the hand, which at first sight looked real, is in fact artificial, we experience an eerie sensation"(99). In addition, Mori highlights that although movement is a "fundamental" imperative of all life, it could, when applied to objects towards the "bottom of the uncanny valley", cause the "sensation of eeriness" to intensify (99).[107] Bode (2019),[108] Furniss (1998), and Wells (1998) have all observed how stop-motion, through its inherent relation to reality through physical objects that are given artificial life despite their natural inanimate state, lends the technique an organic, uncanny quality.

In Charlie Kaufman and Duke Johnson's film *Anomalisa* (2015), central character Michael is unable to decipher the faces or voices of anyone in his world, causing him to feel isolated and alone.[109] Prominent film critic Mark Kermode was amongst the first[110] to point out the uncanny

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[107] Mori believed that in an attempt to create robots that were more human, our affinity increased until it steeply declined into the valley. As a valley, however, there is an eventual incline once more in which Mori suggests that designers can reduce the level of "human likeness" toward the first peak and pursue affinity by "deliberately pursuing a nonhuman design" (Mori, 1970:98–100).
[108] As Bode states, "object animation is uncanny in the Freudian sense of resonating with our old childhood beliefs that our toys have feelings" (Bode, 2019:63).
[109] The character is perceived by many to be suffering from Fregoli delusion—a disorder in which the afflicted believe everyone around them is actually a single person—which is hinted at through the hotel name 'The Fregoli'. Kaufman, however, maintains that Michael does not suffer from the condition but that it was the genesis of the original story (Mitchell, 2016). Themes of isolation are common in much of Kaufman's work.
[110] The film garnered much critical discussion, with *The Guardian* alone producing three separate reviews and multiple articles.

sensation present in the film, stating "*Anomalisa* is populated by players whose bodies seem lifelike but whose expressions resemble moving masks, with everyone but Michael and Lisa eerily cast from the same mould". Other than the review's title there is little further discussion on the film's uncanny nature, though Kermode goes onto say how "a heightened sense of fragile life" is created "that perhaps only puppets could hope to achieve" (Kermode, 2016).

Most obvious of the multiple uncanny elements within the film are the plain-faced homogenised characters that surround Michael and Lisa—all of whom have neutral characterless faces, created by 3D printing the amalgamated real faces of the film's crew (ScreenSlam, 2015:3:50) Along with being voiced by the same actor, these characters create an unsettling, othering sensation. Michael and Lisa's faces are also 3D printed yet un-stylised, bordering on "photorealistic" (Shoard, 2015), which edges them towards the uncanny valley. The printed materials further the uncanny sensation, drawing attention to the artifice of the characters by retaining the break-line—the seams across each side of the eye and over the bridge of the nose—of each face, as well as the slight chatter and line texture revealed as faces are swapped between frames (Anomalisa, 2015:00:53:00) [Figure 70].

[*Figure 70.* Close-up of Michael face *Anomalisa* (2015). ©Paramount Pictures/Courtesy Everett Collection]

The puppets, although detailed and animated with particular attention placed on realistic performance, retain their fabricated nature (Brody, 2018) through, as Anthony Lane (2016) recognises, their "big heads, short stubby limbs [and] skin like fuzz" (Lane, 2016). Theology professor David L. Smith notes that "everyone's gait is a bit halting. Their clothes are ill-fitting, as doll-clothes tend to be" (Smith, 2016:18–19). The fabricated nature of the world is drawn into narrative focus when Michael looks at himself in a mirror and witnesses the lower half of his face flicker, unnaturally cycling through faceplates in an inhuman way, revealing the process and the puppeteered nature of both the film and his existence (*Anomalisa*, 2015:00:32:46–00:33:06). Another sequence, later revealed to be a dream, sees various homogenised characters declare their love for Michael, who flees. Whilst running, the lower half of his face comes away and falls to the ground; the shocked Michael momentarily holds it in his hands as it cycles through replacements, before re-attaching it and continuing his quest (01:07:00–01:07:20). Finally, towards the end of the film, Michael begins to find minor flaws in Lisa's personality, followed by her voice and face changing to that of the homogenised others, leaving Michael alone and without hope (01:12:20–01:14:28). Reflecting on Michael's "sudden sense of horrified perspective" that mirrors the audience's own sense of unease, critic Peter Bradshaw posed the question "what if everyone is just a robot-puppet—including you?" (Bradshaw, 2016). *Anomalisa* strays into the uncanny, but presumably purposely.

By sitting between "photorealism" and "stylisation" (Mitchell, 2016), Kaufman and Johnson were prewarned of the potentially uncomfortable nature of "too real" puppets. However, as Johnson insisted, they did not believe this to be a concern:

> The unique thing about stop-motion is that it's infused with organic life, because it's not made by a computer, it's not perfect—the hands reach in, and they move something. No matter how perfectly you animate something, as you're watching it, it's undeniable—you feel it. There's an organic life that's present in these inorganic things. It feels creepy, and sometimes you're like, "That's a doll!" That's not the same thing. (Romney, 2015)

In another interview, Johnson denounces the idea of the "purist" process in stop-motion or the "rules or limitation" that it promotes. This breaking from tradition, as he saw it, was at least partly due to working with Kaufman:

> He doesn't have any of those inhibitions. So we were able to kind of invent this new approach. I think that's why it doesn't look like anything else, which is one of the things I think we're most proud of. (Mitchell, 2016)

Thus, we can surmise the use of 3D printing was not in pursuit of perfection—or, as Smith (2016) suggests, the "trompe l'oeil effect"—but as an example of "fool [of] the mind" in which the film's artifice is openly displayed "in order to heighten the pleasure we take in our suspended disbelief" (2016:18–19). This, along with *Anomalisa*'s visual uniqueness and narrative symbolism, heightens 3D printing's worth by pushing at the margins of the uncanny using sophisticatedly rendered faces but stopping short of falling into the valley itself. This, however, is not the only way of producing interesting 3D printed animated works. The final section of this chapter will look at ways in which 3D printed materials themselves are used as a reflective medium, both for visual and narrative potential.

7.4 Advantageous Limitations: Post-Digital Aesthetic, Glitch Art, and Sloppy Craft

As an alternative (or addition) to the hyper-real, perfect, or broadly uncanny qualities of the previous examples, we can reflect on how 3D printers and their materials can be more consciously considered regarding their own innate attributes. Animation, as Wells acknowledges, is a "deeply self-conscious medium"; when "not calling attention to the limitations of photographic realism, it is recalling its own codes", "convention[s]" and "developing new ones" (1998:182–83). Films like *Duck Amuck* (1953) and *Flatworld* (1997) highlight their own artifice by demonstrating the rules and structures of animation within the narrative itself, reflecting a post-modern sense of knowing, through the use of meta-storytelling, self-referential humour or "self-figuration", drawing attention to the animator within the film itself (Furniss, 1998:70).[111] Some early examples of 3D printing within stop-motion used similar conventions; *Het Klokhuis* (2010, section 2.2), *Unbox Yourself* (Goodstein, 2014), and *Bears on Stairs* (2014, section 2.2.1) reflect on 3D printing's ability to bring the CG world into physical space, showcasing the hybridity that new technology offers, as *Het Klokhuis* director Johnny Kelly explains:

> I really like work that blurs boundaries, so you don't know if it's CG or stop motion. […] People said, "Oh, why didn't he just make it in CG?" [but] for me, there are a dozen different reasons why we didn't. […] it was a show about science it made sense to have a science experiment as the title sequence and they really like the idea of it. […] The shiny finish of the apple was quite important to me […] there's just something nice about

[111] As discussed in previous sections and highlighted by Mihailova (2021b), LAIKA is also well known for its "self-reflexivity" regarding both the process of stop-motion and reference to other historical/classic filmmakers (59–75). Dan Torre (2021) highlights how in the narrative of *Coraline* (2009) multiple references are made to the replacement techniques used throughout, and the characters are "replaced" either by cloth dolls or by "other" versions of themselves in the alternative world (Torre, 2021:101–03). Torre also notes further elements such as the exposed armature of the "other mother", the use of "button for eye", "stuffed dogs", and characters filled with "sawdust" that disintegrate all of which indicate the fabricated and ultimately puppet world the characters inhabit (108–9) As Torre states, "replacement animation functions as an important metanarrative in *Coraline*. […] A unique metaphysical formation which gives solid real-world forms a unique plasticity" (Torre, 2021:111–12).

> that juncture of digital/analogue. […] [But also] when you take a 3D model and print and then paint it quite roughly it's kind of the best of both worlds. I find that quite exciting […] [and] really appealing. With *Bears on Stairs*, for example, there's […] something hypnotically beautiful about the texture of 3D print, which is its own unique thing.[112]

These textures have their own "visual tactility", as Yekti (2017a) points out; the lined texture of the objects and minor surface imperfections showcase the physicality of the work, denoting a return to the "charm" often associated with stop-motion that reveals the involvement of the animator (Yekti, 2017:128–29).[113] These imperfections and tactile qualities can be seen as the object's "aura", which McCullough describes as "a unique accumulation of responses to material imperfection" through a "record of tool usage" in which the "authorship or origins" of its creation are found (McCullough, 1998:166). Wells (1998) suggests stop-motion is "directly concerned with the expression of materiality" (90), with experimental films particularly predisposed to ideas of materiality through unique visuals or narratives often evoked by "emergent technologies" offering novel and "innovative approaches to animation" (45). Reflection on the organic qualities of materials—that include flaws, glitches and/or imperfections—and the potential to utilise these for visual/narrative construction and aesthetic perception can be understood through three conceptual design ideologies: post-digital, glitch art, and sloppy craft.

As Cramer (2015) explains, the prefix in post-digital is not the same as post-modernism (as in "after" modernism). Instead, it more akin to "post-punk" as a "continuation of punk culture in ways which are somehow still Punk, yet also beyond Punk" or "postfeminism" as a "critical revise continuation of feminism, with blurry boundaries with traditional, un-prefixed feminism" (14). Post-digital is the ideation that we "no longer [focus] on technical innovation or improvement of digital technology", rejecting the "techno positivist innovation narrative" (20), instead proposing a point in which our enchantment with digital systems and devices becomes "historical" (13). In this way artistic practitioners select "media" for its "own particular material aesthetic qualities'' regardless of their analogue or digital origins, through which "digital

[112] Interview with Johnny Kelly, personal correspondence, 19th February 2020.
[113] This notion of charm is discussed by Yekti in his 2015 paper "Comparative aesthetic study between three dimensional (3D) stop motion animation and 3D computer graphic animation", suggesting that imperfect materials or textures draw the audience and film closer together and that it is these perceived imperfections that are regarded as "charming" in stop-motion animation. Ann Owens (2021) uses "neuroscientific research" as a way to explain how stop-motion film, through its ability to simulate "implied actions […] actions that we do not see, but that leave behind some kind of visible evidence" (141) such as carved textures or cracked paint on a puppets surface. In addition, "implied gesture[s]" in how "the human brain simulates grasping and manipulation actions" simply by observing "graspable or manipulatable objects such as tools" affects our visual understanding of the medium (142).

glitch[s]", "jitters", "grain", "dust", "scratches" and other imperfections are embraced to create hybrid objects and works (20–22). These post-digital principles are exemplified through the dual concerns of glitch art and sloppy craft.

A glitch can be best understood as "part of [the] everyday visual engagement of computers" (Betancourt, 2017:1). Glitches present themselves in a multitude of ways, from pixelated images, strobing, flickering, compression issues, visual anomalies, or "artefacts" to audio abnormality such as static, volume changes and unintentional mechanical or digital sounds, which draw attention to the "medium" itself (7). More often a consideration in the study of music or new media art, visual glitches and "technical failures" demonstrate an "engagement with mechanical, automated processes and the (mal)function of machines" (21).[114] In order to utilise these "misfunction[s]", an understanding of the technology remains necessary in order to gain a balance between "predictable" and "chaotic" results (31,37). By skilfully using glitches within the process, the audience becomes aware that these anomalies are part of a "controlled, human choice", in turn challenging the perception of the automated nature of glitches (39). The use of Glitch as a visual narrative device can be seen in multiple animated works, include Will Anderson's *Betty* (2020) and Eamonn O'Neill's *I'M FINE THANKS* (2011), wherein fabricated glitches signify their characters' emotionally charged moments. Glitches can also indicate that a work has "failed" or is "broken", subvert notions of "perfection" in "commercial work", or challenge "capitalist value" (60–64). As Betancourt highlights, each new medium is "defined precisely by those effects that are unique to it", making glitches the "revelation of digital materiality" (3).

Craft holds a paradoxical position, being primarily associated with skill or perfectionism but also with DIY craft, considered kitsch or tacky. The term "sloppy craft", coined by Professor Anne Wilson, occupies "a binary of opposition" that "defies and possibly flips established hierarchies of value" (Wilson, 2015:xxv). Wilson suggests that the "sensorial experience" of "materiality" and the "mark of the hand" that emphasises "imperfections" may be a reaction to the omnipresence of digital screens and media today (xxvi). She emphasises that sloppy craft is not about prevailing "sloppiness or perfection" but instead promotes a more conscious use of craft

[114] As Betancourt (2017) mentions, such "glitches" are neither new nor a purely digital phenomenon in art; the "material dimensions of [a] glitch" are reminiscent of the fetishization of the "artist's hand in historical materialist art" (7)—as discussed in section 7. 2—as well as a "recurring theme of avant-garde art in the twentieth century" (21).

"conceptually" (xxvi).[115] Reflecting on the seemingly amateurish elements or faux-naivety present in sloppy craft—as problematised by the inherent skill, in either process or comprehension, that is necessary to achieve the desired result—Glenn Adamson (2008) states that "the dirty secret of sloppy craft [is] there may be nothing so difficult to pull off convincingly" (199).[116]

Lilly Husbands (2019) notes that an interest in "unconventional production techniques and materials" within animation is often linked with individual artists' "personal vision and creative process" (Husbands, 2019:51) and that for the "skilled amateur" a "conventional notion of perfection is one of many aesthetic choices to be ignored or subverted" (60). Animation as a craft is beholden to the same constraints as any other form; as a "refined skill" that demonstrates "mastery of technique" preoccupied with "perfection", exemplified through the homogenised mainstream of Hollywood entertainment (62). Animation can subvert this by occupying a post-digital position, through both glitch art and sloppy craft, choosing "intentional imperfections" that represent appreciation and understanding of both digital and analogue materials and processes. This does not deny technical skill but shifts focus to using technology in an alternative fashion as a form of "resistance to the slick illusionism of mainstream animation"[117] or as a reflection on the "cultural value of the handmade", "immediacy" or "authenticity" (51–62). The idea of the handmade being more authentic or containing an "autographic mark" is, as Brigit Hosea (2019) argues, somewhat "outmoded" in positioning the artist above all else (34). Animation is a highly collaborative medium (see chapter 5) and thus much of the work—even at the most auteur end of the spectrum—relies on an "allographic" approach, in which work is done by multiple people (35).[118]

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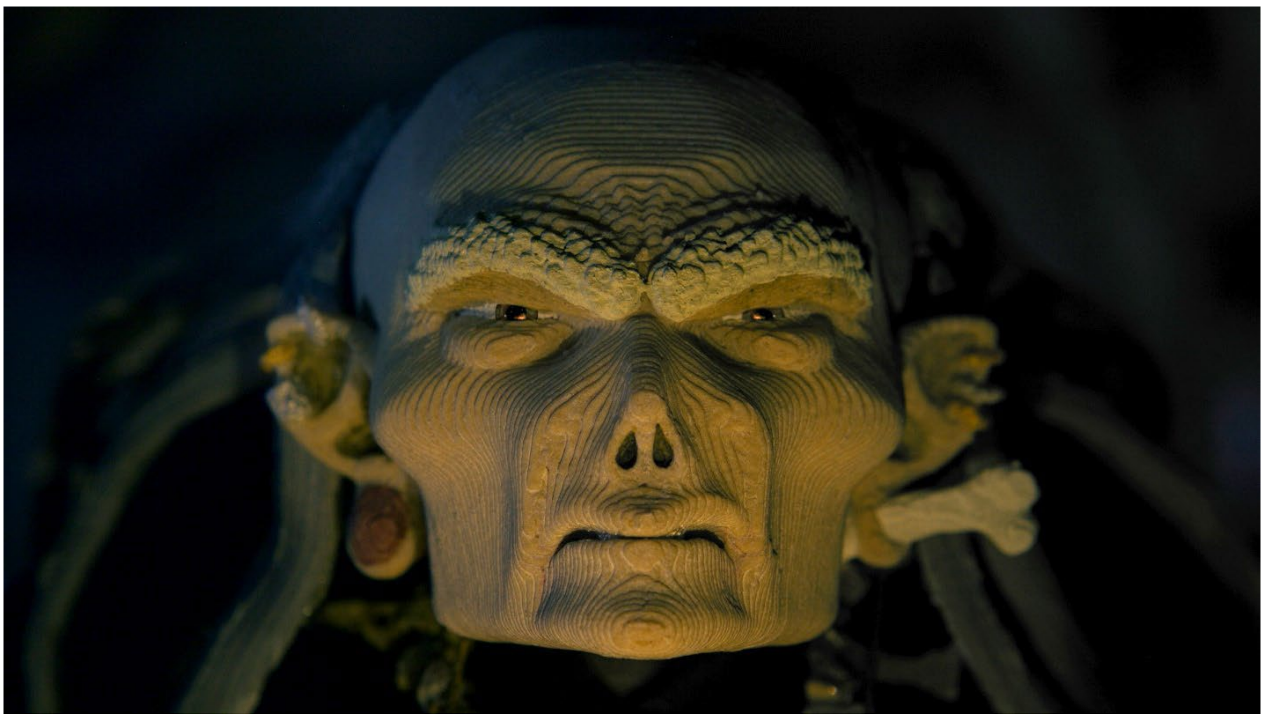
[115] Wilson is quick to point out that sloppy craft is not an opposition to a well-crafted artwork or object, and to believe so may very well be "non-inclusive" to aesthetics that sit between these two perceived binaries (Wilson, 2015:xxvi).

[116] A duality that Adamson contends is a result of the "post-disciplinary environment in which students are trained today", wherein students only learn skills as and when required (200).

[117] The film *Ugly* (2017) is a good example of this. Director Nikita Diakur described it as "a combination of puppeteering and dynamic computer simulation […][varying] between physically accurate and broken" (2019:222), which challenged the animators to strike a "balance between staying in control and leaving enough room for randomness"—a system that Diakur and his team often found "frustrating" but also liberating, producing work that was both "spontaneous" and "unique" (2019:222). Hosea highlights that by subverting "commercial software" the team were able to "produce critically aware animation that interrogates digital materiality" and did "not fake its origin" (Hosea, 2019:40).

[118] Hosea indicates that production that relies on physical production values such as stop-motion are perceived as being somehow free of "mechanical perfection" or automation, but notes that all forms come with their own "automatisms" (Hosea, 2019:36–38).

As highlighted through post-digital glitch art and chapter 3, there is much technical skill required to engage with digital tools, but once combined with real-world processes, both analogue and digital skills are required to hack, innovate and experiment to tell evocative stories in visually unique ways. A film that exemplifies this is *Bone Mother* (2018) by Dale Hayward and Sylvie Trouvé. An eight-minute stop-motion film produced by The National Film Board of Canada, based on the ancient Slavic folk tale of Baba Yaga,[119] the highly stylised use of 3D printing is reminiscent of both sloppy craft and glitch art, by creating work that emphasises the perceived imperfections of 3D printing that are often hidden or removed, to glorious effect (Cowley, 2018).[120]



[*Figure 71.* The face of Baba Yaga in *Bone Mother* (2018). Images provided by the NFB]

The film is a dark, ancient story, predominantly set in woodland, surrounded by trees and organic life. At first this seems an odd subject to link with the modern process of 3D printing, however the organic visual texture FDM 3D printing produced gave a tactile surface finish that proved influential over the entire film. As Trouvé explains:

[119] A supernatural creature who is most commonly depicted as a crone or elderly wise woman.
[120] The directors recently coined the phrase “Limitation as intention” (Bone_Mother, 2021) as a way of describing the processes.

> 3D printing was really ideal because we wanted her to feel so wrinkly and with a traditional mould that would be really difficult to do to that extent […] she felt kind of topographical, in the woods and ancient. This new technology seemed to fit so well to this old story that was set in the 15th century, which was really amazing. (Cowley, 2018)

As well as allowing for a range of expression, this "topographical" look present in the titular character is one of the first examples to use the innate, textual quality of 3D printing not only for visual but also narrative effect.[121] By using FDM machines, printing the faces flat on the bed and reducing the resolution, "larger steeping" between each layer created "deep wrinkles" on the face of Baba Yaga, making the process all the more appealing (Hayward, 2019), as Hayward explains:

> Through the limitation of the printer, we made an intention with her face; it gave it a handmade feel […] in retrospect [we] could have gone back and limited our rangers even further because of the […] printer [quality] there [were] some face[s] on Maya that looked like there was a big difference between, but in reality you couldn't tell the difference. [They were] all hand painted as well, […] [giving them] more of a boil, which […] we wanted to embrace. (Cowley, 2018)

[*Figure 72.* Vlad *Bone Mother* (2018). Images provided by the NFB]

[121] Another early example can be found in section 2.2.1 *Happy Camper—Gravity* by Job, Joris and Marieke.

This visual proved so effective that similar texture profiles were used throughout the film. By varying the layer line depth, a range of textures were created and used for props such as skulls, bones, the house, and the other character [Figures 72 and 74], whose face was more refined but retained noticeable layers:

> [3D printing] allowed us to get a large production look with a small team. At max, it was five of us but most of the time it was just Sylvie and me. It allowed us to have two different scales of the house, tons of bones and tons of modelling [without] moulds. […] We also printed the chest blocks and their pelvis padding around legs and the arms […] We found if we heated [the material] with a heat gun, we [could] shape it, so we also shaped Baba's hunch and tried to shape her as we were going. (Cowley, 2018)

By printing replacement hands, they maintained the texture developed for the face and animated them using heat to manipulate the material directly, allowing for further levels of subtlety and nuance (Cowley 2018). Other novel materials were explored; clear filament was used for the bones and skulls, which were scorched, aged, and lit from within to give a haunting, ethereal appearance. A flexible filament with wire added post-print to prefabricated "trenches" was used for possible hair. A pinewood PLA filament was selected for its "porous" surface so the directors could hand-finish the faces with watercolours, with little to no sanding required (Hayward, 2019; Cowley 2019).

[*Figures 73.* 3D printed hands heated and manipulated on set. Image used with thanks to Dale Hayward and Sylvie Trouvé]

The extensive use of materials in their raw states, along with Hayward and Trouvé's willingness to physically warp, burn and otherwise destroy the printed materials, subverted the often-pristine image of 3D printed objects as precious, delicate, expensive, and highly processed miniature artwork by seeing them not as finished, rendered frames ready to be captured by the camera, but as raw materials ready to be manipulated in the hand of the animator once more. Treating the printer as a tool to create repeatable shapes that can be altered or manipulated directly on stage, utilising imperfection as an exciting new tactile phenomenon. This film perfectly reflects the tandem concepts of both glitch art and sloppy craft, as post-digital concerns that explore materials for their initiate qualities.[122] As Cramer notes, a perfect example of post-digital work makes use of the "technology most suitable to the job" to create hybridity between "old and new", to maximise the benefits of both (Cramer, 2015:24).

[*Figure 74.* Behind-the-scenes images exploring the use of 3D printing materials in *Bone Mother* (2018). Image used with thanks to Dale Hayward and Sylvie Trouvé]

122 Another film, *Ties* (2019) by Dina Velikovskaya, makes use of a 3D pen to tell a story of family bonds. By using plastic filament and drawing three-dimensional frames, Velikovskaya is able to combine her monochromatic 2D drawn animation and 3D stop-motion skills into a hybrid process that reflects a truly post-digital attitude towards material and skill. The material is used poetically to mirror the connection between parents and child; as the child leaves home a continues thread of filament follows her on her journey, reminiscent of the apron string or the umbilical cord of infancy. As both parties begin to unravel, they must return to one another to become whole again. Velikovskaya makes use of both the material and the more direct process of 3D printer pens to brilliant effect in this beautiful film (the3doodler.com, 2019).

7.5 Alternatives to 3D Printed Facial Replacements

There are of course multiple alternative ways of creating facial animation within stop-motion that were used both before and after the advent of 3D printing. Clay animation has long been used as an expressive medium, particularly in facial animation (Purves, 2010:108; Torre, 2021:99) and is still used today at studios such as Aardman for shows like *Morph*. “Clockwork”, geared or mechanical heads produced for films like *Corpse Bride* (2005) and *Fantastic Mr Fox* (2009), using miniature gears and paddles to enable minute facial expressions (Salisbury, 2005) still offer a unique level of detail, as seen Jean-François Lévesque’s film *I, Barnabé* (2020) (LIAFanimation, 2020). Lévesque says:

> I chose to use mechanical heads because, in a working context, it’s more fun and creatively much more stimulating. With a puppet-like Barnabé, what you have is a real little actor who can do everything, with no extra bits that have to be added or taken away. It’s easier to feel free, to improvise and let yourself go. And because there were only two animators working on the project, it was possible for us to take this approach. (Cowley, 2020)

More experimental ways of animating faces include compositing real eyes, as seen in *Madame Tutli-Putli* (2007) and S*even Minutes in the Warsaw Ghetto* (2012), or in *Friendly Fire* (2008) wherein live-action faces were projected onto puppets (Purves, 2010:94–103). Filmmakers have used digital hand-drawn faces or mouths composited onto stop-motion characters as seen in *Edmond* (2015) and *One Liner* (2019). There are times when handmade replacements not only suffice for the minimal changes needed in production but in some cases are preferred, such as Wes Anderson's 2018 film *Isle of Dogs* (McLean, 2018). As discussed in section 2.1, replacement facial features can also be created using other digital tools such as laser printers for stickers or digital embroidery for fabric replacement. Some filmmakers choose to have one static face throughout relying purely on the eyes to emote, as seen in *Tchaikovsky, An Elegy* (2011) and *Next* (1990).

[*Figure 75* Left - Still from *The Supporting Act* (2017). Right - still from *All Through the House* (2021). Images used with thanks to Blinkink]

In a step, perhaps beyond the potential of 3D printing, Elliot Dear's use of CG composited faces achieves further levels of subtlety and potentially perfectionism. Motivated by the desire to reach Pixar levels of nuanced performance, pursued through the economic and time restraints of short-form commercial projects, Dear and his team developed the system for the 2017 BBC Christmas ident *The Supporting Act*. The system was used again in 2021 for the first stop-motion episode of the anthology series *Love, Death + Robots*[123] (Cowley, 2021), allowing Dear full control even after the final frames had been shot. In this regard, this may offer the biggest potential change moving forward in the development of facial animation for those seeking hyper-realism, ultimate perfectionism, and control (Cowley, 2021). When asked what this process brought to him as a director, Dear stated:

> Nuance. I think anyone who works in stop motion will know that puppets have their limits and I think lots of people embrace that. […] Aesthetically, what I like is just shy of realistic. Stop-motion puppets that have dots for eyes and mouth shapes that snap into place are obviously going to work perfectly in camera but I'm yet to see a puppet that has a mechanism that can do the things that I wanted them to do. 3D printing is interesting, and everyone's entitled to make things the way they want […]. To me, it seems like quite a complicated process. […] Also, there is still an element of stylization in the movement because those face shapes are going to snap a little bit, from one to another, there are going to be texture variations. LAIKA obviously do incredible work with their clean-up, it's very finely tuned. But what I want is even smaller, really little facial expressions and things because that's the types of performances that I like and it's not until you get on the computer, and you start moving things around in CG and the difference between the eyelid being moved is a fraction but changes the whole expression. You can go from uncanny to charming, or the movement of eyebrows can

[123] "All Through the House" (Series 2, episode 6).

> be worried or not, through these tiny, tiny little movements. I would say it's about control; I love the control. (Cowley, 2021)

In this way, we can see that 3D printing, like all the methods described above, is just another aesthetic choice that relies largely on the requirements of the project and the imagination of the creator.

7.6 Concluding Thoughts

As Furniss recognised back in 1998, media and technology are chosen by the "artist" when they desire a "certain quality in his or her work" (1998:64). In this way, we can understand all the aesthetic considerations presented in this chapter as a choice that lies squarely in the hands of the makers. 3D printing is just one of a full range of techniques on offer. 3D printing can produce forms of hyper-realistic, near-perfect animation that borders the uncanny. The continued development of technology—a push to fine-tune the tools and expand the possible materials available as well as combine them to create new, mixed-property materials—can lead to original, innovative creations. There is also the potential for the technology to be surpassed or remediated by other processes, such as those presented by Eliot Dear and his team. Alternatively, a more reflective, post-digital stance could be explored further—most likely by experimental or auteur filmmakers—taking this technology and exploring its inherent materiality through the dual lenses of sloppy craft and glitch art from a more conceptual, autographic, or personal perspective, making use of organic imperfections as a purposeful, advantageous feature. This consideration will be explored in the final case study presented in the next chapter.

Chapter 8. Case study: Novel Film—*Crafty Witch*

Building upon the previous chapter's discussion of the aesthetic possibilities of 3D printing, this case study explored how 3D printing can be used to create a novel aesthetic profile, through documenting the creation of a short, animated film both to conclude the study and facilitate dissemination of findings within and beyond academic circles. Drawing on themes from previous chapters, this film reflects various definitions of 'craft' by combining analogue craft with digital skills and tools, and the term 'crafty'—as described in *The Crafty Animator* by Caroline Ruddell and Paul Ward (2019:1)—as signifying acts of cunning and deception, which can be read both visually and narratively in the final film.

8.1 Project Outline

The study aimed to produce a one-minute micro-short that used 3D printing as a material to represent two distinct design styles: that of the classic 1950s animation style of cartoon modern (Amidi, 2006), and historic wood block-printing found in early documents discussing the occult and witchcraft [Figure 76]. The combination of styles was inspired in response to the striking but often crude woodcuts of the period, which often used simplified shapes and bold facial profiles which paralleled the design features found in many iconic cartoon modern characters. The case study used 3D printing as the connecting technology to combine these styles. FDM printing, with its noticeable layer lines, is used to create a textured visual profile that approximates the pattern in woodblock printing as seen in Figure 80. Pre-visualization elements were developed in collaboration with a 2D animator, then modelled digitally, 3D printed and animated in stop-motion, combing all three primary forms of animation. This study enabled me to enact and document the full process of using 3D printing replacements in a film, as well as receive feedback from a range of industry professionals. The aims and objectives can be seen in Table 10.

[*Figure 76.* Image taken from *The History of Witches and Wizards* (1970). Wellcome Collection. Public Domain[124]]

Aim	To create a short, animated film with a novel use of 3D printing built into the design, to explore the aesthetic potential afforded by combining styles, and technology.
Objectives	• Collaborate with a 2D animator to create cartoon modern characters. • Create a texture profile within the body of the prints using 3D printing. • Engage with the physical activity of creating a replacement animation film, with multiple replacement parts to gain further practical insight into the creative and labour considerations of working with an extensive replacement library system. • Engage with industry participants to evaluate the quality of the work and test whether the aim and objective were met. • Submit film for various festivals, conferences, and exhibit events to disseminate working methods to broader audiences.

[*Table 10*. Aims and Objectives for Novel Film Crafty Witch Case Study]

[124] Image is included in a document that is in the public domain and can be found at: https://wellcomecollection.org/works/abkab8tq. Credit: The history of witches and wizards: giving a true account of all their tryals in England, Scotland, Swedeland, France, and New England; with their confession and condemnation / Collected from Bishop Hall, Bishop Morton, Sir Matthew Hale, etc. By W.P. Wellcome Collection. Public Domain Mark

In this case study, I was to be both researcher and director. In contrast to the previous case study, I would be predominantly responsible for the creative decisions and labour associated with making the film, with only the pre and post visual elements created by others. As the aim of this study was to develop a short, animated film with a novel use of 3D printing built into the design, it was important for me to have a larger, more active role in the practical development of not only the puppet components but the process of animating and cinematic decision making throughout.

8.2 Cartoon Modern as an Appropriate Visual Style

The cartoon modern aesthetic is visible in the work of various animators and studios throughout the 1950s; as Amid Amidi (2006) explains, it represented several distinctive art styles that were influenced by modern art, cubism, surrealism, and expressionism (7). The art style embraced the medium of animation, rejecting the circular and oval based character of earlier designs such as those created by Disney and featuring modern design elements such as hard-edged shapes and lines (8–10). These design features were incorporated into the movements of the characters, often distorting them frame by frame before returning them to their original state. Others kept specific body parts still while performing through the limbs or other parts of the character, in a method known as limited animation, something that became popular in the industry as a cost-cutting measure (11). These concepts were also brought into the background design by abstracting the character's environment, relying heavily on flat colours and white space or using larger painterly strokes, emphasizing the handmade artistic nature of the work. The energetic and playful nature of the carton modern style has had a long-lasting appeal and impact on the language of animation that often goes unrecognized, due to its wide range of design features and short-form format. Thus, it was a perfect design style to recreate with 3D printing.[125]

8.3 Selected Processes

The style and process were selected in tandem to explore the potential for replacement animation, such as creating squash and stretch movements whilst maintaining all other visual

[125] The cartoon modern style has been created in stop-motion before but often relies on either plasticine or hand carved replacements similar to those created by George Pal in the 1930s.

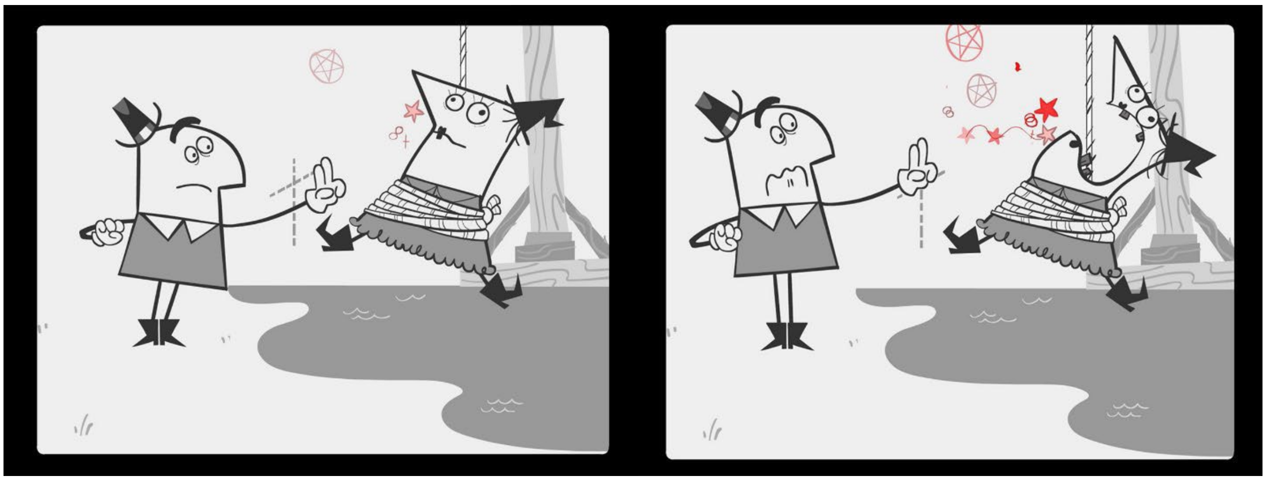
considerations. As with all animated works it is important to set out working methods or rules, to apply a logic to the design principles moving forward. Only puppet elements would be 3D printed, to create replacement parts with varying texture profiles and to differentiate the character from background and foreground elements. Table 11 explains each process.

Heads and bodies	FDM printing using an adapted ender 3 with HERO 5 hot end adaption (MediaMan, 2020) was used to create the body and head elements of the puppets, as these were to be large and solid. The use of organic layer lines created by the printing process was used to create a bespoke texture profile through the process, in essence using the selected tool of 3D printing for its organic visual materiality.
Hands, eyes, eyebrows, mouths, shoes, and hats	SLA printing[126] was used to create puppet components that required a detailed, high-quality surface finish. SLA printing was used for both characters, to enable a flatter less textured surface finish. The witch's hair and eyelashes and some of the thinner facial parts such as eyebrows, thin mouths, and squinting eyes were created using a mix of paper or oven-fired polymer clay, as they would be unlikely to survive the SLA printing process.
Backgrounds, clouds, and water droplets	These elements were created using paper cut replacement as minimal replacements were required and to expedite the animation process. This was also a more authentic representation of the backgrounds in classic cartoon modern design.
Arms and legs	The limbs were created with wire and built-up layers of latex impregnated foam (Murphy, 2008:78–9), to create flexible rods that could be cut to length when required in the sequence. Limbs could have been created as 3D printed replacements, but wire allowing for subtle movement and adaptability on set, as well as reduce time and labour associated with removing the puppet between every frame.
Other	The final, more surreal, or ethereal elements—such as the dotted line left by the making of the cross of the hunter [Figure 77] or the expletives/symbols coming from the mouth of the witch [Figure 78]—were created digitally to allow them to float and fade in/out of visibility.

126 Formlabs 1 and 2 SLA machines were used with standard grey resin.

	This could have been created in paper cut or by using SLA printing, but the thinness of the shapes and the need to have them fade in and out would still have required digital effects, so they were composted in post-production.

[*Table 11.* Film Processes]



[*Figure 77.* Left – dotted line of cross. *Figure 78.* Right – visual incantation of the witch. Images used with thanks to Sam Shaw]

8.4 Working with Collaborator Sam Shaw

Once initial designs, storyboards and basic animatic were created,[127] I as researcher/director contacted collaborator Sam Shaw to develop the final pre-visual materials. Shaw is an animator and director at the Bristol-based studio Sun and Moon, and his personal work has been shown at multiple international festivals including Pictoplasma, an event that highlights the inventiveness and importance of character design.[128] Sam is well known for his character design and regularly incorporates the cartoon modern style into his work, which made him an ideal collaborator.[129]

[127] A storyboard was first created by the researcher with initial character designs and animatic frames created by fellow animator Hannah Stevens. The final animatic created by Shaw can be found in the folder “Chapter_8_CraftyWitch” that accompanies this thesis.

[128] More information about Pictoplasma can be found on their website; https://pictoplasma.com/about/

[129] I had first become aware of Sam’s work when I attended his BA Degree show in 2013. Having spoken to Sam in the past at local industry events, further conversation raised more personal reasons for his invested interest in collaborating on the film. Sam, having lost one of his eyes at a young age, has a reduced level of depth perception, which in turn hindered his ability to pursue a career in stop-motion. Working on this project enabled him to be involved with a stop-motion project. Although not a

Shaw was to develop the pre-visualization of the film, from which all components would be designed. In our initial meeting, we outlined considerations that needed to be addressed regarding physical construction to negate issues further down the line. This included incorporating interconnecting parts to aid with registration when animating, which was achieved by keeping the bodies of the characters consistent, with minimal changes throughout the film. This required that most of the movement be achieved though the heads, hands, and limbs, in a performance akin to limited animation. Shaw, through his knowledge of cartoon modern movement, performance, and timing, produced a highly detailed 2D animatic[130] that could be broken down and rebuilt in three dimensions, allowing for a pragmatic working process with less potential for error.

8.5 Initial Feedback—Linoleum Animation Review

In June 2020 I was selected to take part in an animation review panel at the Linoleum Contemporary Animation and Media Art Festival in Kyiv, Ukraine. The online events consisted of a pitching and feedback session for a current stop-motion project in development, with two industry experts: Tim Allen, an exceptional and prolific stop-motion animator and director who has worked on many of the most prominent stop-motion productions of the last two decades—including *Isle of Dogs* (2018), Oscar-winning short film *Peter and the Wolf* (2006) and *Corpse Bride* (2005)—and Irida Zhonga, an animator and director based in Athens, Greece, whose work spans short films and commercials with expertise in mixed media animation production. Through this review panel, I was to present the film's narrative, styles, and novel process, and to receive feedback.

Perhaps the most important piece of feedback received during this process was that both experts assumed the film would be filmed flat, using a simple multiplane set-up. Although this was not initially the idea, I developed the film in this way moving forward, as it elevated a lot of issues such as shadow, rigging and rig removal. The panel agreed that the project had merit and Tim Allen spoke highly of the level of detail in the animatic, regarding it as an incredibly

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consideration within the scope of this project, it is perhaps interesting to note the potential avenues the use of a hybrid or collaborative working process offers people with certain physical, mental, or other health considerations.

[130] The animatic can be found in the folder "Chapter_8_CraftyWitch" that accompanies this thesis.

useful resource. They understood the origins and combining of the two styles and were intrigued by the novel use of 3D printing as a process. Both were aware of 3D printing use within the industry but neither had worked with the technology directly.

Further suggestions were made regarding the potential of developing the project into a series and how this may be achieved. The process was seen as a good way of creating a repeatable and potentially cost-effective series, that could largely be done by one animator with a small amount of space and equipment. The highly energetic style of the piece was also highlighted as an enjoyable component of the film, noting that care should be taken to express these movements in the animation by increasing the level of ‘snappy’ posing in shots. The panel offered a great opportunity to not only gain further insight into the film at the start but to highlight potential creative working methods that may better realise the vision for the film moving forward.

8.6 Data Logs: Replacement Breakdown and Layer Height

As with the previous case study, a detailed data log documenting the entire case study was kept throughout.[131] In order to break down the animation into its component parts, the animatic was rendered out into individual frames and put into a table, with each replacement element labeled and cross referenced for duplication, and double, triple, and other multiple frames removed.[132] A separate table was created to indicate each replacement part that needed to be created in CAD.[133] At this time, I was simultaneously testing variable layer heights and printing parameters. Using a simplified 3D shape I conducted extensive testing for nozzle sizes, printing settings, and print orientations to determine how far the layer height could be pushed and still maintain functionality. This was done to increase the visibility of the individual layers without creating holes or other unwanted anomalies within the printing process. There are settings for nozzle height and temperature that are pre-determined to give the best results; normally defined as creating a high-quality, strong piece that is fast to print, as these are the perceived advantages of using a larger nozzle size in FDM printing. Visual qualities are rarely considered beyond a desire to make it appear 3D printed. However, as my intention was to use these naturally formed ridges for the aesthetic potential, it was important to test these parameters to their fullest.[134]

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[131] The case studies data log can be found in Appendix C.1.
[132] A breakdown of the animatic can be found in Appendix C.2.
[133] A breakdown of replacement components for each character can be found in Appendix C.3.
[134] A full log of this testing can be found in Appendix C.4.

An Ender 3 FDM printer with a Hero Me Gen5 upgrade was used to allow a stronger, more heat resistant hot end, that could push more filament at the correct temperature through a larger nozzle to be applied. Extensive testing was undertaken to reach a balance between distinctive line making and print anomalies or failures due to layers not fusing to one another. This meant pragmatically testing various settings in the slicer software (Cura). A final selection of a 1.2mm nozzle with a 1.0 layer height was chosen. By reducing the speed and increasing the temperature, printing at this layer height was achievable with consistent layers and without developing gaps or extensive flaws. When printing with a larger nozzle the need for internal infill was not necessary. An issue with over extrusion on the initial layers was noted as it created a noticeable warping which would cause the heads and bodies of the puppets to interlock rather than slide together. By fine-tuning the bed level and increasing the bevel on the base of the digital model, the issue was removed completely, leaving clean prints that were able to fit together with minimal post-print sanding.

8.7 Sculpting

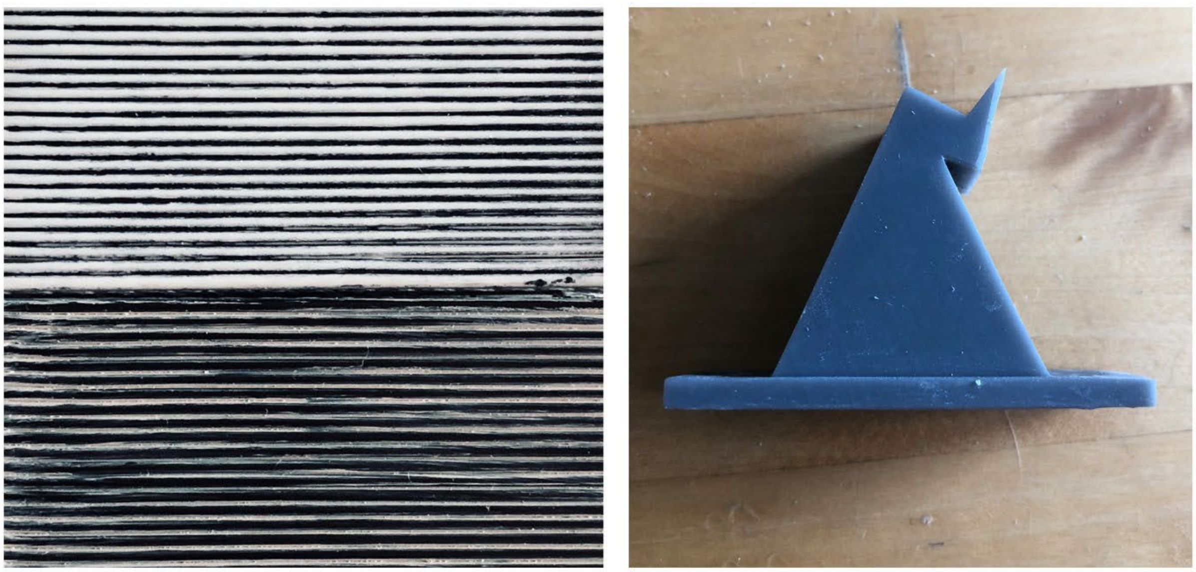
Once all potential puppet replacement parts were labelled, each piece was created as a 3D model using CAD (Autodesk Fusion 360). The characters designs with their angular geometric designs were well suited to CAD modelling software. Although possible through any computer modelling software, the combination of functionality, angular design, and carved aesthetic led me to select CAD software for the creation of all 3D design elements.

[*Figure 79.* CAD modelled hand]

The body, as the single element that remained largely unchanged throughout the film, was the starting point for each of the puppets, from which all other measurements were taken. Small details such as collars and buttons were recessed into the face of the body to create a valley for paint once printed. Holes for limbs were also added at this point. The heads were designed to fit into the body recess, both to give depth and aid with registration on set once animating. All the edges of the head were given a slight bevel to create a smooth finish, a more exaggerated bevel at the base reduced the potential for initial print layers over extruding. Images of the individual replacement were used to trace and plot the initial digital sketch, before extruding and adding additional details. The final shapes were scaled to make sure proportions were correct across both puppets and all the replacements.

8.8 Printing

The prints were printed upright to create a uniformity in the line pattern texture. They were largely printed without the need for support except for the few heads of the hunter in which the nose was suspended at a 90° angle. Due to the layer testing the printing was quick, with multiple heads being printed at the same time and only minimal reprints required. The SLA printed facial components and accessories were printed in standard grey resin. It took six to seven hours for full beds of objects to be printed.[135] Some parts were reprinted due to small errors in the final prints, partially due to the age of the materials that had been left as sediment during the multiple national lockdowns and a small internal flaw perceived to be due to something (most likely dust) on the glass optical window which caused a single hair width line to be created in all prints on a certain part of the bed. Multiples prints were created in case of any unperceivable issues which may have arisen during the post-processing or filming such as breakages or losing parts. The prints were soaked in isopropyl alcohol (IPA) before fully curing in a UV light chamber.



[*Figure 80.* Left - FDM printing texture. Right - SLA printed part]

8.8.1 Post-processing

Once all prints were completed, various post-processing techniques were applied to colour, bring out the texture and/or apply details to the prints. The bodies had acrylic paint added to the buttons, collars, and belt details. Small holes or drooping layers that had occurred during the printing process for the heads, predominantly in areas of extreme angle change such as the mouth and nose, had a small amount of air-drying epoxy putty added to fill the holes; this was

[135] All parts were set up using Formlabs' PreForm slicer software. Unnecessary additional printing details—such as file names from the bases—were removed, support bases were merged, and print beds were filled as much as possible to help reduce the overall printing time. Having multiple machines working at the same time also aided in expediting the process.

done not to hide the anomalies but to stop the spaces creating dark spots when lit during animation. Each head was then coated in shoe polish before being burnished to highlight the natural grain created by the printing process, the polish sat in the valleys of the print. Black acrylic paint was also used on the sides of the heads to add depth and highlight the design features of the puppets.

[*Figure 81.* Hand in stages]

The SLA prints had all supports removed, then small surface scratches and bits of debris were removed using fine sandpaper and water. They were then cleaned using isopropyl alcohol (IPA) as water leaves a powdery residue on the prints. These prints were then painted in either black or white acrylic paint, using a sponge to create a flat matt finish. Hands were back painted to highlight depth in the design. The teeth and lips were painted to separate them from the back of the SLA printed mouths, which were left in the pure grey resin.

8.9 The Filming Process

Once all components had been made, I set up a shooting space within the university's dedicated stop-motion lab, allowing me access to frame capture software (Stop Motion Pro), set lighting and a rostrum set-up.[136] As the film is one continuous thirty-second sequence, the entire film was shot over two days. The first day of shooting consisted of just over half the film, leading up to the cloud transition. The second included the cloud transition and dunking sequence. The process was straightforward; overlaying the animatic helped keep track of timing and posing for each frame of the animation. There was room to make small creative changes on set, to help with the visual clarity of shots or push individual poses to emphasize the ease, bounce, squash and stretch of movement in the film (i.e., small incremental movements were possible between

[136] As the film was shot flat, I was able use a very small space of around one by two meters.

the head and body due to the overlap and space between the parts). The process was enjoyable, and the range of parts created in the pre-production stage allowed for full creative control, largely because I had created everything so had made sure to give myself the best possible range of parts and in between elements.

The duality of the replacement process means that although it is creatively satisfying to have pre-created parts that offer extreme poses and physical changes in a puppet (without the labour of sculpting each frame or making small gestural changes in various elements of the puppets face, hand, and/or body), the need to replace multiple elements between each frame or remove the puppet entirely from the shot to make alterations produces a lack of organic ‘flow’. Rather than being able to push, pull, or otherwise manipulate the puppet from movement to movement, the replacement process feels more stilted and mechanical. Although a perceivable drawback, no stop-motion or indeed any animated technique is without its less satisfying procedural requirements.

8.9.1 Documenting the Making Process: *Making of a Crafty Witch*

A making-of or behind-the-scenes video documenting the entire study was created to aid in dissemination of the project, but it also offered an opportunity for reflection.[137] Like all documentaries, decisions must be made before shooting and at the editing stage as to what is—or, perhaps more importantly, what is not—going to be present in the final film. It was decided that the film should have no voices, narration or statements from the research or collaborators but instead should represent a material lead process, with minimal written notes explaining or describing the various processes and stages of production. Once the film was completed the various pieces of footage taken during the project were put together to honestly represent the linear process of making the film. Labels were added to differentiate tasks and aid in future dissemination presentations. This was done to showcase the processes to a wider audience and highlight the complexity 3D printing adds in the production of a short, animated film.[138]

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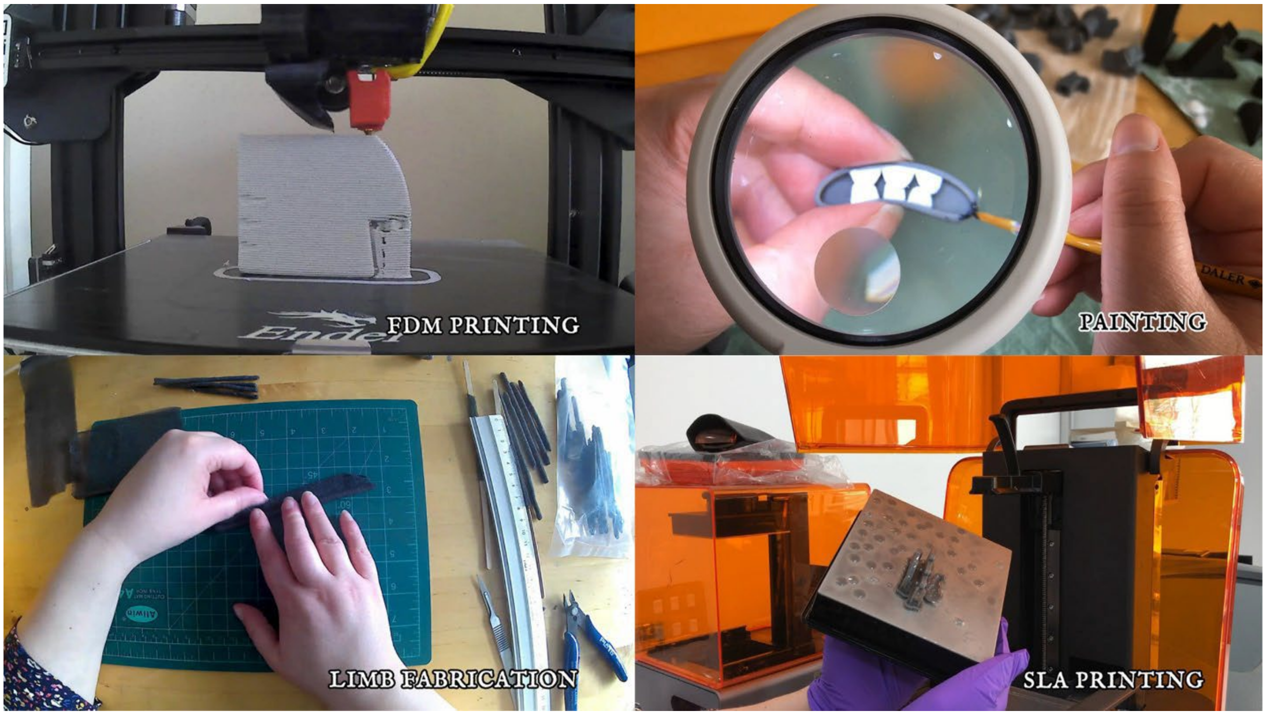
[137] During this study, I conducted research into the use of video as viable dissemination and practical research method in documenting and presenting the holistic working methods during the process; this research was presented as part of the Essay Film Form and Animation: Intersectionality in Motion conference (Cowley, 2019b).
[138] The making-of film can be found in the folder ‘Chapter_8_CraftyWitch’ that accompanies this thesis.



[*Figure 82.* Still from *Making of a Crafty Witch* (2021)]

8.10 Practitioner Review

After concluding the filming sound, music and post-production, film grain and filters were added to give the film an early cinematic look.[139] The film along with the making-of video were sent with a simple questionnaire to a select group of willing industry participants and experts.[140] The participants were selected for their knowledge of the animation process and their invested interest in advancements in the industry [Table 12].

Sam Shaw	Case study collaborator, animator, and filmmaker with specialist knowledge of the cartoon modern style.
Tim Allen	Prominent stop-motion animator and director, who was also one of the experts on the animation review panel at the Linoleum Contemporary Animation and Media Art Festival.

[139] The final finished film can be found in the folder 'Chapter_8_CraftyWitch' that accompanies this thesis.
[140] The completed questionnaires can be found in Appendices C.5.1–4.

Luis Cook	Senior animation lecturer at the University of the West of England, BAFTA-winning animation filmmaker, previously a director at Aardman Animations. His work incorporates elements of both 2D and stop-motion, often requiring replacement techniques.
Adam Taylor	Animator and filmmaker based in Portland, Oregon, USA who has worked at various studios including HouseSpecial and Netflix's *Wendell and Wild*. He was also a member of the animation review panel of the Linoleum Contemporary Animation and Media Art Festival, for his own project.

[*Table 12.* List of Review participants for Novel Film Crafty Witch Case Study.]

Based on their responses, I concluded that the story and visual styles were well represented. Feedback indicated that the blend of styles and technology fulfilled the aims of the film, even possible deceiving or hiding the process from the audience, creating an 'ironic' interplay between new and old technology:

> It's beautifully animated – a fabulous collision of old and new [...] I'm not sure you would know that the artwork had been 3D printed – it looked hand made. Which is exactly what you want 'aesthetically' from this process. You don't want to go and see a stop motion film and think it's been made by robots – it would lose its charm. It's ironic – using such high-tech stuff to produce something so handcrafted.' (Luis Cook, 2021: Appendix C.5.3)

[*Figure 83.* Still from *Crafty Witch* (2021)]

Sam Shaw noted further interplay between the visual and narrative construction of the film on reviewing the completed film, by recreating historical or 'past' design styles, but unifying them through modern technology:

> Combining two very different stylistic approaches using a medium that hasn't been used broadly to represent them before is not an easy task, but the limitations and attributes of 3D printing have […] been used to celebrate both art styles […] I love how both styles obviously link to the past but are brought to life using incredibly modern tech - giving the visual style a unique creative life of its own. (Sam Shaw, 2021: Appendix C.5.1)

The reviewers emphasized the uniqueness and appropriateness of using 3D printing and stop-motion together, to combine these styles:

> I feel that this is a well thought out use of different approaches to 3D printing & combining the techniques. The animation movements & character designs are so distinctive that it makes the wood grain a subtle effect rather than a key feature. (Tim Allen, 2021: Appendix C.5.2)

It was noted that the use of different 3D printing technologies and materials gave more visual intrigue through subtle differences in textures for different parts of the puppets:

> The mix is great! You can definitely feel the different textures which makes it even more interesting to watch. (Adam Taylor, 2021: Appendix C.5.4)

As well as the painted detail added to accentuate the styles represented in the film, further developing the combination of styles into a singular visual language:

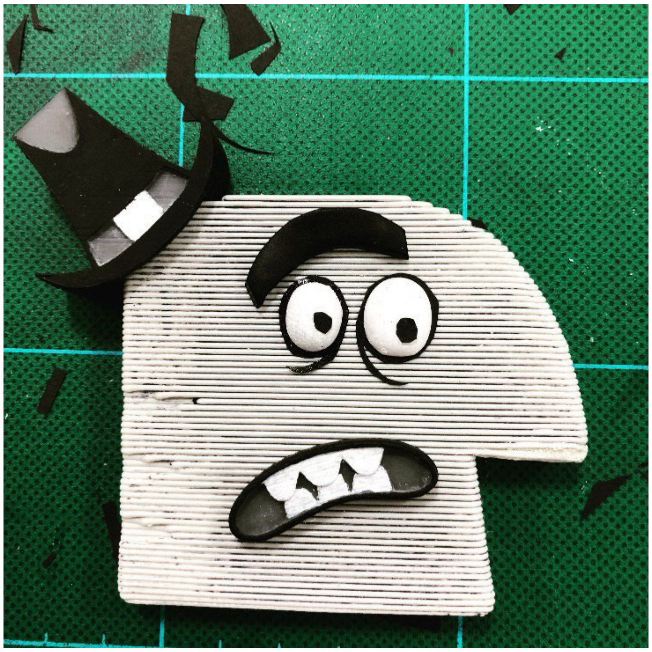
> I do like the mix of grainy areas & smooth surface areas as part of the 50's cartoony look. The cartoons of the 50s that you are emulating did indeed have a bold simplicity to them which the smooth areas reflect well. I also appreciate the bold outlines you give the characters in keeping with the 50s style. (Tim Allen, 2021: Appendix C.5.2)

Most of the participants suggested an increase in the 'wood grain', citing it as "subtle" and having the potential to get "lost in the cut […] [and] thrust of dynamic animation" (Tim Allen, 2021: Appendix C.5.2). The width of the nozzle and filament were almost equal to one another, which meant I was essentially printing at its full diameter, which was the widest I could achieve with the technology available. To push it further would have resulted in prints failing due to a lack of time for the filament to heat up and adhere to itself. In future, I would like to develop a method of creating controllable imperfections and failures in prints, to explore a more fluid, organic use of the material. However, the angular shapes and the need for parts to fit together for registration purposes in this film meant parts had to remain structurally sound and consistent.

There is also the possibility that the reviewers are confusing the idea of a woodcut ‘print’ aesthetic, in which the pattern transferred through the wooden block comes from the carved sections and not from the grain of the wood itself, as Allen suggests:

> There could even be an obvious argument to carve the replacement faces out of real wood! However, from a production standpoint, the current approach is efficient for making future episodes that would hope to use duplicates of the same parts, especially if additional animators & setups would be required. (Tim Allen, 2021: Appendix C.5.2)

This infers that I was seeking to mimic the more organic imperfections of wood grain, which was not the case for this project. In future, if this was the desired surface texture it could be sculpted into the surface of the print much like the triangle nicks denoting depth that were created on the side of the puppets’ heads [Figure 84].



[*Figure 84.* Head detail]

Further useful feedback was given regarding developing the project into a series and what consideration may be taken to achieve this. Much of what was concluded was that the film succeeded in its aim to blend a combination of styles. The use of multiple 3D printed materials and technologies aided in creating a unique aesthetic that although potentially still achievable using traditional methods, proved beneficial in terms of creativity, efficiency, and accuracy of vision.

> The look & feel is instantly appealing & grabs the audience's attention then goes forward to raise smiles & leave you satisfied. It is a very enjoyable watch! If anything, the audience will not appreciate all the work that has gone into the process & the labour taken to create the replacement parts. I'm very glad that you've made the 'Making of' to accompany it & allow your effort to shine. (Tim Allen, 2021: Appendix C.5.2)

A concluding statement was given by Cook, expressing the ways in which the technology could be used in his own style and that the work developed during the study was of a similar standard to the work created within the studio system.

> It looks great. A very professional finish. I have worked in this two and a half D way before at Aardman – although not using 3D printing. 1. I would have loved to have tried this technique 2. I can't tell the difference – you'd never have known computers were involved – which is great, it's what you want. The final look and finish of the film are up there with any work I ever produced in this way, probably better. (Luis Cook, 2021: Appendix C.5.3).

8.11 Conclusion

This case study identified the strengths and weaknesses of 3D printing both visually and mechanically, through experiments and practical work, in the development of a novel aesthetic that combined the style of cartoon modernism with early woodblock printing. The selected materials, animation techniques, and subject matter blend to create an appealing, clear, and entertaining film. The film furthers the consideration for 3D printing as a tool with multiple potential roles in the animation process, beneficial in the creation of novel aesthetic profiles, and particularly in combining visual styles. There was a focus on the inherent material qualities and textures 3D printing affords, which may be taken forward for further visual, artistic, and narrative synthesis in future. The additional making-of video aids in disseminating and visually demonstrating the process in the film to a broader audience.

Chapter 9. Conclusion

> The researcher struggles to liberate the reader from simplistic views and illusion. The researcher is the agent of new interpretation, new knowledge, but also new illusion.
> (Stake, 1995:99)

The purpose of this study has been to demonstrate a deep understanding of the technical, visual, and social considerations that digital tools such as 3D printing have produced within the stop-motion animation process. Through both the thesis and practical case studies, I have contributed new knowledge and understanding about how 3D printing has impacted and continues to impact all areas of the stop-motion animation industries. Additionally, these insights are not limited to stop-motion or indeed animation production; the findings presented here have significant importance in other creative and technical industries that make use of collaborative workflows, independent working patterns, digital tooling, and the creation of unique/novel design, for which 3D printing is a valuable tool.

The purpose of this study is not to suggest a right or wrong way of using 3D printing technologies or materials, but to document them; to suggest novel uses and to discuss the social and aesthetic considerations that should be taken into account when creating a pipeline that uses these and other similar technologies. I believe that 3D printing technology and the stop-motion industries have reached a state of maturity; we have moved on from the initial intrigue and are no longer spellbound by the captivating hype of 3D printing. Those who have found a use for the technology are now looking for ways in which to hone and further finesse the process, whilst remaining open to new materials and advancements. Those who continue to use the technology understand its limitations and are building on its strength to create new ways of working in animation production.

3D printing is far from the simple plug-and-play technology that it is often portrayed as being in the mainstream media, but with collaboration, training, and the ever-reducing costs of both machines and their materials, it is not hard to see why this technology will continue to serve as a useful tool in the modelling and animation industries.

9.3 Original Contribution to Knowledge

My contribution to knowledge is represented by a holistic, in-depth understanding of the use of 3D printing in the animation industries, both on a practical level (regarding the skills, technology and material understanding needed to engage with the process) and when it comes to key theoretical concerns highlighted through the enquiry. By combining novel collaborative case studies and interviews with leading experts and independent auteurs, the research presented here provides a considered perspective on the ways in which 3D printing as a tool has impacted the craft skill, authorship, and aesthetic potential within stop-motion animation production. The case studies included in the thesis also stand as works of cinematic art that displayed significant originality in terms of their contribution to the continued use of 3D printing in the creation of animated films.

Through each section of this thesis, I have outlined both the practical and theoretical considerations arising from the use of 3D printing in animation production. From this I have demonstrated various working methods for anyone wishing to create work using this or similar technologies. By conducting comprehensive case studies using action research cycles, the need for rigorous notetaking and documentation has been highlighted throughout and should provide a framework for anyone wishing to conduct research using a similar adapted process of investigation. From students to veteran industry specialists, experienced auteur filmmakers to fellow researchers, it is my hope that the level of detail presented here will inform, engage, and ultimately inspire more creative use of technology within the animation medium.

The interviews and conversations conducted throughout the study with leading practitioners—many of whom have already requested a copy of the final thesis upon completion—as well as the practical and theoretical insights developed will, I believe, further influence how this technology is used in the industry moving forward. Theoretical considerations—particularly those concerned with authorship, levels of control, division of labour, aesthetic potential, and organic material quality—will permeate not only the research but the industry as a whole, offering up new considerations and ideas to those making incredibly sophisticated films and works of cinematic splendor.

9.4 Areas for Further Study

The use of 3D printing is primarily driven by personal choice and technical ability. 3D printing technologies, machines and materials are continuously being developed, which has somewhat complicated the task of finding a satisfactory conclusion point for this study. It has been my aim to give an up-to-date account, with as much detail as possible, of the current use of (and next potential steps for) 3D printing, both within its own industry and that of animation. I have future-proofed my research by providing potential new applications and consideration for work in this field. There is still much more to explore when it comes to the environmental or health and safety positions of the various technologies, as well as a continuation of the work done here to consider the creative possibilities through design, new technology, and materials not yet available—or perhaps not yet even thought of.

9.4.1 Future Aesthetic Potential

I believe there is still significant potential for further creative and aesthetic profile generation through the use of 3D printing and hybrid models of manufacturing. I predict this taking three potential routes:

1. Larger commercial studios will continue to innovate within the technology itself, adapting and increasing levels of sophistication as more materials and 3D printing technologies become available. I expect that LAIKA will continue to be at the forefront of this, due to their established position within the field, their use of a permanent core team and the contacts they have fostered over the years with leading technology companies. They are sure to make use of their extensive skillset to push the technology to its furthest potential.

2. Smaller studios, independent or auteur filmmakers will make smaller, more nuanced developments with the technology—with a concerted focus placed on addressing the materialism of 3D printing, avant-garde filmmaking, experimentation, and tool creation—as well as creating more self-reflective or meta-narrative structures that make use of a post-digital framework.

3. There is also the potential for 3D printing to be remediated entirely by new technology, most likely similar to the work produced by people like Elliot Dear, which combines stop-motion animated performances with CG faces. If nuance, ultimate control, and perfectionism is the pursuit, then such hybrid processes are to be expected.

However, it is more likely that all these suggestions will be realised in the future. As printers and their materials continue to reduce in cost, more opportunities will arise to experiment with the technology. As people become more comfortable with the technology, they will become more willing to gain the skills required to produce their own creative ideas. The 3D printer still offers in its many forms an ideal tool for fabricating bespoke objects and tools, and this fabrication process is only enlivened by its interaction with various analogue skills and ways of making.

9.4.2 Material Considerations

Although outside of the scope of this study (see 1.2), further research could be done into the potential for more environmentally friendly materials and printing processes. This could also be developed into a larger study of other hazardous chemicals and materials commonly used in stop-motion production, of which there are many. The archival and associated issues with maintaining and storing 3D printed materials in future must also be considered. Within the sphere of preservation and archiving, 3D printing—and, more often, 3D scanning—has been used to develop ways of recreating, cataloguing, and exploring the historic and current modes of stop-motion production (see section 3.4.3). For this reason, decisions need to be made regarding storing both the digital and/or physical components, which may include moulds for stop-motion puppets, the untold number of replacement faces being created in productions at studios such as LAIKA, and the issue of cataloguing and maintaining the stability of the 3D printing materials themselves. This may prove an engaging area for further study, not only in terms of revitalising past work, but also in terms of preserving work created today that may require archiving in the future. As a result of the extensive libraries of replacement parts, which can be stored physically or digitally, will the individual objects themselves yield any useful tactile analysis and, if so, what procedures need to be put in place to catalogue and preserve 3D printed materials in the future?

9.4.3 Future Materials and Technology Developments

I have no doubt that as soon as this thesis is published, new materials, technologies and of course animated works will come to light. Innovative new technologies are constantly being used to produce new materials—either by themselves or using complex multi-material combinations—to create hybrid materials and objects with new properties that will stimulate the development of new ideas and inventions. This thesis is one step towards understanding how one particular industry of artists and designers may incorporate this technology into their working practice. I fully intend to keep abreast of these developments and explore ways to incorporate them into my own work (and the work of those I collaborate with) when they become available and have shown themselves to be useful.

9.5 Dissemination

During this study I have contributed to multiple conferences, guest talks, and round tables, as well as lectured, taught, and written for multiple publications on the themes discussed within this thesis as well as on a broader range of topics within animation, film, and the arts (see bibliography). On completing the PhD, I intend to disseminate my research through papers, symposiums, academic conferences, industry talks, film festivals, peer-reviewed journals, and as chapters in collected works on specific subjects related to those uncovered throughout this study. I will also continue to use the practical skills developed throughout this research, both in my own creative work and as a consultant for others seeking to introduce 3D printing or other digital fabrication tools into their working methods.

9.6 Closing Summary

> Research is not just the domain of scientists, it is the domain of craftspersons and artists as well, all who would study and interpret.
> (Stake, 1995:97)

When I first began this study, a level of impassioned naivety prompted me to investigate the potential of a “fully printed puppet”, the hope was to combine armature, flesh, and skinning material through one omnipotent machine. Ignited by the futuristic sci-fi promises of the early books and news articles on 3D printing, I was certain that behind closed doors were high tech machines capable of printing anything I or my excited colleagues could imagine. In reality, what awaited me were equally enthusiastic people toiling away on DIY machines, problem-solving functional errors using ever advancing technology and reams of minutely altered g-code—all of which ultimately proved far more exciting than the futuristic fantasy of the “press and go machines” discussed in the media.

Those working to break down the technical façade—getting their hands dirty by incorporating analogue hand skills back into these (relatively) simple printing machines—provides an interesting new dimension to counter the highly polished perception of 3D printing. It is my hope that through this thesis more people will have access to the requisite knowledge, skills, and confidence to work with 3D printers, and to see them as more than just high-tech machines capable of creating immensely detailed final pieces ready to shoot under the camera. As with other tools and materials, 3D printers also have the potential to create beautifully imperfect objects that can be broken, melted, and manipulated to our creative will.

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Crafting a Crafty Witch (2021) Directed by Laura-Beth Cowley. Vimeo [Video] 16 May. Available from: https://vimeo.com/551256484

Crafty Witch (2021) Directed by Laura-Beth Cowley. Vimeo [Video] 16 May. https://vimeo.com/551204115.

SHACKLE (????) Directed by Ainslie Henderson. UK: BFI.

The Gift (2019) Directed by Laura-Beth Cowley. UK: Calling the Shots/ BBC Arts. Available from: https://www.bbc.co.uk/programmes/p089z7dd

The Life and Times of a Witch Bottle (2020) Animated by Laura-Beth Cowley. UK: Calling the shots/ BBC. Available from: https://www.bbc.co.uk/programmes/p08z33t

Conferences, Symposia Papers and Talks presented in relation to PhD study;

CFPR Seminar: The Making of The Gift [CFPR Lunchtime Seminar] 14 May 2020. Available from: https://cfpr.uwe.ac.uk/cfpr-seminar-the-gift-an-animated-film-about-ancient-powers-and-menstruation/

CFPR Seminar: Crafting a Crafty Witch [CFPR Lunchtime Seminar] 09 December 2021. Available from: https://cfpr.uwe.ac.uk/8-dec-2021-laura-beth-cowley-crafting-a-crafty-witch/

Curse or Gift: a portrayal of witchcraft, menstruation, and female power in the 2019 short, animated film The Gift. [online] Contemporary Folk Horror in Film and Media Conference. Leeds Beckett University, 29-30 January 2022. Available from:

https://www.youtube.com/watch?v=Hweb1Y8hfCo&list=PLKDxI0JOa-WgGmFEHIlKdlrXbjvohFbDk&index=5

*“**Show me what you’ve got”: The ‘making of video’ a multi-sensory and multi-purpose research method.*** The Essay Film Forum and Animation: Intersectionality in Motion. Derek Jarman Lab, 12-13 June 2019. CAPA, London.

The Changing Face of Replacement Animation: How looking to the past can revolutionize the future of stop motion animation. The Society for Animation Studies Annual Conference: Then | Now | Next. Concordia University, 19-21 June 2018. Montreal, Canada.

The Future Is Animated. [online] (MA) Character Animation. Central Saint Martins. 2020/2021

The Future Is Animated. [online] (BA) Animation. The University of the West of England. 08 October 2021.

Visiting Professional Talk: Making it work for you [online]. Leeds Arts University. 4 November 2021.

Film Festival Screenings for Crafty Witch;

Cardiff Animation Festival, HOME, Cardiff, 7-10 April 2022.

Final-Girls Berlin Film Festival, City Keno Wedding, Berlin, 2-6 February 2022.

British Shorts, City Keno Wedding, Berlin, 20-26 January 2022.

Stop Trick, Slovenia 29 Sept – 3 Oct and Poland 6-8 November 2021.

Encounters Internation Film Festival, Watershed, Bristol, 1 – 30 September 2021.

Life Screening One Minute, Orlando Public Library, Florida, 2021.

Minute Madness Toronto, Canada, 2021.

Southern Maltings - 5-minute film festival, Hertfordshire, 2021

Additional writing and interview that have informed this PhD;

Cowley, L. (2017) **Playlist: At Home.** *Marimo*, 1, pp 92-97.

Cowley, L. (2018) **Phantasmagoria: an animated watchlist.** *Marimo*, 2, pp 74-77.

Cowley, L. (2018) **Deep in the Uncanny Valley.** *Marimo*, 2, pp70-72.

Cowley, L. (2018) P**amela Pettler: Breathing new life into the Addams Family mausoleum**. *Marimo*, 2, pp 18-21.

Cowley, L. (2019) **The Essay Film Forum and Animation: Intersectionality in Motion Report**. *AnimationStudies 2.0* [online]. Available from: https://blog.animationstudies.org/?p=3191

Cowley, L. (2019) **Book Review: Crafty Fingers and Imperfect Frames**. *Animation Studies 2.0* [online] Available from: https://blog.animationstudies.org/?p=3421

Cowley, L. (2018) **Interview: Paloma Baeza and Ser En Low discuss the BAFTA-winning 'Poles Apart'**. *Skwigly* [online] 12 January. Available from: https://www.skwigly.co.uk/poles-apart/

Cowley, L. (2018) **Q&A: The Musical Animations of Heather Colbert**. *Skwigly* [online] 23 March. Available from: https://www.skwigly.co.uk/heather-colbert/

Cowley, L. (2018) **Interview with 'Clangers' director Joanne Chalkley**. *Skwigly* [online] 21 May. Available from:https://www.skwigly.co.uk/joanne-chalkley/

Cowley, L. (2018) **Unraveling 'Orange is the New Black' with Špela Čadež.** *Skwigly* [online] 5 June. Available from: https://www.skwigly.co.uk/spela-cadez-oitnb/

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Cowley, L. (2018) **Nexus tells an epic stop-motion story of Corona's Mexican history**. *Skwigly* [online] 28 March. Available from: https://www.skwigly.co.uk/nexus-corona/

Cowley, L. (2019) **'Missing Link' Review**. *Skwigly* [online] 5 April. Available from: https://www.skwigly.co.uk/missing-link-review/

Cowley, L. (2019) **Q&A with 'Strike' director Trevor Hardy**. *Skwigly* [online] 10 May. Available from: https://www.skwigly.co.uk/trevor-hardy-strike/

Cowley, L. (2019) **'The Art of Missing Link' book review**. *Skwigly* [online] 22 Aughust. Available from: https://www.skwigly.co.uk/art-of-laikas-missing-link-book-review/

Cowley, L. (2019) **"Farmageddon: A Shaun the Sheep Movie" set report**. *Skwigly* [online] 17 October. Available from: https://www.skwigly.co.uk/farmageddon-set-report/

Cowley, L. (2019) **Q&A with Sam Shaw ('You Died!')**. *Skwigly* [online] 13 November. Available from: https://www.skwigly.co.uk/sam-shaw/

Cowley, L. (2020) **Stop-Motion Filmmaking – Book Review**. *Skwigly* [online] 11 February. Available from: https://www.skwigly.co.uk/stop-motion-filmmaking-review/

Cowley, L. (2020) **Interview with Ali Aschman, director of 'Shadow Passage'**. *Skwigly* [online] 09 June. Available from: https://www.skwigly.co.uk/ali-aschman-shadow-passage/

Cowley, L. (2020) **Interview with 'Just a Guy' director Shoko Hara**. *Skwigly* [online] 02 July 2020. Available from: https://www.skwigly.co.uk/shoko-hara/

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Appendices

A.1 - Project Log: Long-form Pilot Study Material and Joint Design

A.2 - Further Analysis of Reviewed Papers from the Initial Pilot Study

A.3 - Material Analysis Log

B.1 - Project Log: Auteur filmmaker eye mechanism – SHACKLE.

B.2 - Original email sent to Collaborators.

B.3 – Conclusion Interview Transcript.

C.1 – Project Log: Novel Film - Crafty Witch

C.2 - Animatic Breakdown.

C.3 – Replacement Breakdown.

C.4 – Nozzle Layer Height Analysis Log

C.5.1 Crafty Witch Questionnaire – Sam Shaw

C.5.2 Crafty Witch Questionnaire – Tim Allen

C.5.3 Crafty Witch Questionnaire – Luis Cook

C.5.4 Crafty Witch Questionnaire – Adam Taylor

D.1 List of Interviews Conducted for study

D.2 Copy of Participant Information Sheet

D.3 Copy of Participant Consent Form

D.4 Copy of Image Permission Request Form

Appendices A.1 – Project Log: Long-form Pilot Study Material and Joint Design.

Project Name	Joint - Material
Participants	Laura-Beth Cowley, Dave Huson
Date	28/5/2020

Activity	Recreate joint design 3 to start looking at fabricating the joint using SLA printing and lost-wax process for metal parts.
	
	Re-design original joint design 3 with better tolerance understanding - hereafter known as version 9_?
	
	● Version_9
	    ○ Simple design based on 10mmball, with 1.5mm cup and 0.2 tolerance
	● Version_9_tap
	    ○ Same as above plus joined tap spot 3.3mm for post processing addition of grub screw 2M
	● Version_flex
	    ○ Slightly extended cup to allow for enclosed hold
	
	To be sent to Sofie for lost wax SLA printing, to then be sent to AA for casting in brass at £7 per piece.

Time	40mins
Date	29/5/2020
Activity	Contacted Sofie for update: She is waiting on wax, reason for new designs Tweaked version_9 to increase internal circumference of cup to 10.4 so tolerance is 0.2 -Also created scale version at 0.55 and 0.8 and sent to Fabio for SLA test Tweaked version_9_ tap - increased internal circumference of cup to 10.4 so tolerance is 0.2 and adjusted tap accordingly Tweaked version_9_flex - increased inside cup by 0.1 to have no tolerance between cup and socket.
Time	2hrs
Date	6/7/2020
Activity	Picked up prints from Fabio; Version 9 and version 9 flex have been printed with no way of telling between

	minute tolerance differences, as there are slight anomalies between prints due to support meaning accurate testing of the individual design is not possible. However, it does show that these minute changes don't equate to much as all the joints don't hold well or aloft. Going forward I think zero tolerance would help with any joints that are to create a tight hold. Version 9_0.8_scale: Slight anomalies between prints but also minor faults due to supports creating movement. Issues could be resolved with sanding but overall, the cup skirt length and thus the hold it has on the cup is an issue, creating a weak system Version 9_0.55_scale: Similar issue with previous scaled version. Reducing scale helps with tolerance as it is reduced, but the skirt issue is also greater as the scale decreases, creating a weak joint system that would not hold to much movement. version_9_ tap: Joints sit together nicely; increased tolerance allows for easy but loose assembly. Tap indent not useful, would be better as a full hole to help with threading. Overall tap I think is too small in circumference and due to the fragility of the material will probably bore badly.
Time	30mins
Date	20/7/2020
Activity	Sent files to Sam to print. ● Joint_9_tap_version 3_0.55 ● Joint_9_version 2 ● Joint_9_version 2_scale_0.8 ● Joint_9_version 2_scale_0.55 To see how they print with grey resin on the Elegoo printer to see if it warrants better results or difference in print quality joint _9_tap_version 3_0.55 to try and different scale
Time	10mins
Date	1/9/2020
Activity	Received prints from Sam. She printed flat on the printer bed so with no support but added a small hole inside of prints to allow for resin release in print. Slight lip/foot inside cup and possibly slightly reduced detail of printing have equated to a tighter fit. When working on snap fit joints a very delicate balance must be met in terms of tolerances and clearances to create functional parts, working in solid material makes minute changes tricky.

	Joint_9_version 2 - very tight fit, slight lip inside entry to cup. When the joint is moved around and some additional uncured resin is loosened from the surface, the joint becomes looser. Good hold and fit may become looser over time. Joint_9_version 2_scale_0.8 - Similarly, tight fit is harder to put together - smaller scales are incredibly brittle overall - if they do manage to go together, they break under pressure or strain. Sam suggested adding some flex in with the abs material. Joint_9_version 2_scale_0.55 - Hard to put together, if put together skirt length is an issue to create good hold and movement. If forced together using doll pliers, the brittleness is an issue causing it to break instantly. Joint_9_tap_version 3_0.55: Same as above, hard to snap together, when forced breaks, scale makes threading redundant and unfeasible. Next step - if there is an option to work in a mixed flexible material into the solid abs resin it would be worth trialing, however reflecting back on work done so far on this project the best results are still found in the initial pilot study which uses FDM and work in polyflex. Waiting to get prints from Sofie from cast trial in metal but, ultimately, I believe flexible materials may still be the best move forward for this style of joint. Although reducing the cup angle was originally suggested early on it does create problems regarding keeping the links together. Slits were also suggested early on, but this decreased the strength of the overall object. Mixing of material in FDM were trialed extensively, as were resins, but ultimately found to not work due to various reasons. The next step for this project should be to reduce the tolerances and ready the joints for flexible STL printing. It may be worth doing further testing using SLS technology reportable stronger materials, but this draws potential issues due to texture and lack of material choice (mostly rigid).
Time	30mins
Date	29/10/2020
Activity	Sofie received casted joint and is sending them on. Sending over revised Joint_9_tap with increasing tap circumference by 0.5 and internal thread hole by -0.1. File name joint_9_w/tap_v4 Sending over revised Joint_9: with increased internal cup by 0.1mm As well as revised joint 9 in 0.55 and 0.8 scale.

	File name joint_9_v3 et al for 0.55 & 0.8 To test her printer's tolerances and the material. Next steps: ● Redesign flex joint to increase internal cup to create tight fit. ● Increase skirt length to hold better ● Create scale iterations ● Send for SLA flex and elastic printing. ● Check revised joints from Sofie, revise and read about SLS tolerance requirements.
Date	2/10/2020
Activity	Preparing to send flex joints to GoPrint3D Looking at older tests of flex from initial pilot study using FDM increasing internal cup thickness from 0.1spacing. Increase using press/pull by 0.3mm. Making it have no space and 0.2mm overlap to aim for a tight fit/create suction. Version_9_flex Version_9_flex_0.8 Version_9_flex_0.55 Sent to get printed in flexible, elastic and durable Formlab SLA. Found example on Formlab website: https://formlabs.com/eu/blog/durable-resin-available-now/ Found a print company that offers SLS printing in nylon and flex and MJF printing to get the non-flex joints printed in the materials below. MJF Nylon PA12 - Natural/grey MJF Nylon PA12 - Polished/ black SLS PA2200 Nylon - Natural/White SLS PA2200 Nylon - Polished/Blue Colours just picked to differentiate between materials and finish In order to reduce costs, I have attached the joints into one row with a thin bar 0.509 to keep them together - this may break during printing and or finishing but I would hope the company would raise this as a potential issue. I have included Version 9 - *with 0.1mm tolerance the scaled version scale accordingly* Version 9_0.8 Version 9_0.55 Version 9_w/tap - *Tap increased to 4.359, whole 0.68. + Made tolerance*

	space 0.1 Flex will be printed in SLS Flexible - Natural/neutral The flex joint has also been developed into a single group with a bridge Version 9_flex - *with the new overlapping tolerance as seen above.* I have uploaded these joints to 3DPRINTUK which is now being manually reviewed for any issues. Possibly worth trying a pre-assembled version 9 with elongated cup to keep fully enclosed for SLS printing.
Time	2hrs
Date	4/11/2020
Activity	First Quote from GoPrint3D: Was quoted £153 with VAT, asked for a new quote for grouped flex joints in three scales developed for SLS/MJF print. Received new quote for SLA printing from GoPrint3D; **Durable 0.1mm - x1 of each part / all on one build** Total cost £24.30 Ex VAT Not included support removal **Flexible 80A 0.1mm - x1 of each part / all on one build** Total cost £20 Ex VAT Not included support removal **Elastic 50A 0.1mm - x1 of each part / all on one build** Total cost £33.32 Ex VAT Not included support removal Total: 77.62 = £93.14 - Still pretty pricey (£1.72* a piece)
Date	5/11/2020
Activity	Reply from 3DPRINTUK dated 2/11/2020. They seem to think the joints will work but asked to check tolerances and

	clarify how to identify the different prints after printing. Replied explaining I'm doing a feasibility study, that there are 3 designs normal (with 0.1 tolerance gap inside cup), tap (with an additional added tap for post print threading), flex (with a -0.2 tolerance to create a tight fit). That flex and Normal also have additional half and third scales. I want normal and tap files to be printed in SLS nylon and MJF. There are in essence 12 of each file and so half should be treated/finished differently so 6 of each in SLS should be polished/dyed blue and 6 natural/white 6. 12 MJF files 6 should be polished/dyed black and 6 left natural/grey. SLS flex should just be identified by scale as no post processing is available/needed You should be able to tell the difference due to scales. Further conversation about tolerances and finish and survival of joint in post processing polish (quite an aggressive process) Meeting Dave on Monday 11am discuss these new findings. Notes for meeting. **SLA** Elastic, expensive, worth seeing results of other materials first? **SLS/MJF** Sprue currently 0.5 is it worth an increase to 2mm? Polish process rough - maybe just try it on a normal scale? 0.8 and 0.55 scale may be an issue 0.55wall is 0.8/ 0.8 wall is 1.3/ normal wall is 1.6 *also discuss mould making for test casting of limb
Time	20mins
Date	9/11/2020
Activity	Dave meeting notes; Increase outside volume of 0.55 for SLS/MJF printing to 1mm to increase positive printing. remove polishing versions of 0.55 and 0.8 - Dave has a polisher to try at the university if I want to trial later.

	Hold off on Elastic for SLA and see what result you get with Durable and Flex. - - - - Increased outer wall thickness of SLS/MGF standard version 9_0.55 to 1.09mm Further discussion with 3DPRINTUK suggested increasing sprue to 2mm. Also, that polish wall thickness needs to be 1.5mm After further discussion increased sprue on all versions to 2mm and decided to negate polish as the scale of joint is unlikely to survive the process. Discussed also printing separately which would increase once again overall quality (no attachments) and safety of the parts as treated and tracked as separate entities. However, as these are only tests this increased individual piece to £1 per joint until a quality break is met (approx. 50) This is to test material strength and joint
Date	11/11/2020
Activity	One final note from 3DPRINTUK was to increase the tap hole to 2mm, as I intend to thread this, I have increased it by -0.66 to create a whole of 1mm. In turn I have also increased the space around by 0.321 to take the wall thickens to 1.35. I have replaced and ordered tests. £56.34
Date	27/11/2020
Activity	Received prints from both GO3DPRINT and 3DPRINTUK. Initial looks like a mixed result, will be reviewed fully soon.
Date	21/1/2021
Activity	Analysed prints from bureau can be found in Joint Study Material test log [appendix A.3]. Purchased M2 & M2.5 grub screws to test tapped joints as well as plastic display cases.
Date	11/2/2021
Activity	Finally able to add grub screws - used M2.5. Grub screw and tap placement makes for uneven tensioning - causing the joint to be pushed out. May be worth trying with more straight alignment. Durable material SLA proved to be a lot firmer than expected should try with a non-flexible version. Second set of resin printed SLA with wider tap - with whole through SLS with new aligned tap - and polished

	MJF with new aligned tap - and polished **Version_9_w/tap_group_2:** Increased internal cups by 0.05 make tolerance 0.05 as every version bar the SLS PA2200 Nylon lacks a tight fit **Version_9_group_2:** Increased internal cups by 0.05 make tolerance 0.05 as every version bar the SLS PA2200 Nylon lacks a tight fit. This has reduced the 0.8 and 0.5 tolerance by half. Have requested quote for each and 0.55 and 0.8 version in SLA rigid 10K and 400, tough 1500 and 2000, as well durable and pro grey- should hear back on Monday So far polished and unpolished version of version_9_/witap_group_2, Version_9_group_2 as well as unpolished versions of Version_9_0.8_group_2 and Version_9_0.55_group_2. Comes to; £24.20 + £15.80 +VAT£8.00 =£48.00 (£15.80 to top up to minimum spend of £40 - so looking for anything else worth getting tested)
Time	2hrs
Date	12/2/21
Activity	Want to test various iterations of design(s) for SLS printing **Version 9_w/tap_grouped** **V2** = change of tap position and tolerance reduced by 0.5 **V3** = change of tap position with no change to original tolerance changed **V4** = change of tap position with longer cup by 0.5 **V5** = change of tap position with longer cup by 0.5 and tolerance reduced by 0.5. **Version 9_grouped** **V2** = tolerance reduced by half **V3** = increased cup length by 0.5 **V4** = tolerance reduced by half and increased cup length by 0.5. **Version 9_grouped_0.8** **V2** = tolerance reduced by half **V3** = increased cup length by 0.5

	V4 = tolerance reduced by half and increased cup length by 0.5. **Version 9_grouped_0.55** **V2** = tolerance reduced by half **V3** = increased cup length by 0.5 **V4** = tolerance reduced by half and increased cup length by 0.5. **[additionally a 10x10x2mm label has been added to each group with v number]** Have uploaded to 3DPRINTUK waiting on review of **Version 9_w/tap_grouped_3** to see if it would survive polishing due to the new label. They believe it will break so I have taken the polished version out. Subtotal:£ 46.35 VAT @ 20%:£ 9.27 Total Due:£ 55.62 Paid 12/2/2021
Time	6hrs
Date	3/3/2021
Activity	Received Prints today- to analyse on 5/3/2021 and order SLA versions [never heard back from GO 3D PRINT about this]
Date	5/3/2021
Activity	Reviewing results from new iteration tests of SLS Nylon Prints with natural finish. **Version 9_w/tap_grouped** **V2** = change of tap position and tolerance reduced by 0.5 Snaps together well, with reasonable hold. After tapping with M2.5 x 6 grub screw, once tightened still comes loose - angle of tap insufficient. Additional pressure from screw distorting cups may prove a problem over time. **V3** = change of tap position with no change to original tolerance changed After tapping with M2.5 x 6 grub screw, once tightened still comes loose - angle of tap insufficient.

	V4 = change of tap position with longer cup by 0.5 Good tight fit on the assembly, snaps together well. Addition of grub allows for complete rigidity of joint, tolerance can be altered to create tighter fit, however this raises issues with scraping the internal ball as it is still only nylon and potential concerns due to access depending on where and how the joint was to be used. **V5** = change of tap position with longer cup by 0.5 and tolerance reduced by 0.5. Similar functionality to V4 slightly looser clipping together before addition of grub screw. Creates tight hole once added, can be taken apart once fitted, but causes scrapping and damage to the internal ball. **Version 9_grouped** **V2** = tolerance reduced by half A far more robust hold, tight ‘snap/pop’ fit, with a good range of movement, motion, and rotation. Vastly improved from the last batch at this scale, however, will still come apart if rotated too far. **V3** = increased cup length by 0.5 Great hold, slightly looser movement than with V2, however it doesn't come apart as easily and the rotational difference is minute between V3 and V2. **V4** = tolerance reduced by half and increased cup length by 0.5. Rather disappointed this has the worst hold of the three. Fits together well and rotation is good, but it doesn't stay aloft like V2 and V3. This is strange as at worst it should have been too tight by combining the attributes of both models. Either there has been a slight alteration in the printing process, or the file is incorrect - **Have checked the file and the tolerance between the ball and socket are V2- 0.05 / V3 - 0.1 and V4 - 0.04** **Version 9_grouped_0.8** **V2** = tolerance reduced by half Far more robust hold, tight ‘snap/pop’ fit, with a good range of movement, motion, and rotation. Vastly improved from the last batch at this scale, however, will still come apart if rotated too far. Slightly better hold than Version 9_grouped_V2 **V3** = increased cup length by 0.5 Very snug fit, snaps together well and rotational hold is good you would have to apply quite a lot of force to make it come apart. Overall better performance

	than Version 9_grouped_0.8_V2 **V4** = tolerance reduced by half and increased cup length by 0.5. Snug fit, snaps together well and rotational holds are also good, if not a little looser than V3, I still feel that over time the tensioning may decrease, leaving the system flaccid and unusable. **Version 9_grouped_0.55** **V2** = tolerance reduced by half Won't really snap together and if it does it comes apart if moved. **V3** = increased cup length by 0.5 Snaps together and some rotation possible but comes apart easily. **V4** = tolerance reduced by half and increased cup length by 0.5. By far the best result but will still come apart easily if rotated sharply or to far.
Date	11/3/2021
Activity	Meeting with Dave to discuss finding from the further SLS printing, agreed that anomaly with V4 is most likely an issue that has arisen from minute changes in printer bed. **No further testing required of SLS printing technology.** Have requested all prints to be priced by Go3DPrint in; Durable Rigid 10K Rigid 4000 Tough 1500 Tough 2000 grey pro Rebound Waiting to find out the cost.
Date	12/3/2021
Activity	Received quote from Go3DPrint for SLA tests. I didn't ask for flex but this may have come under rebound materials. This is for all versions and each material takes up two beds.

NO.	ITEM DESCRIPTION	SKU	PRICE	QTY.	SUBTOTAL
1	Bureau Print	GOPBUREAUPRINT-P1	109.30	1	109.30
NOTE: qty 13 Durable Resin 0.1mm - Excludes Support Removal					
2	Bureau Print	GOPBUREAUPRINT-P1	78.04	1	78.04
NOTE: qty 13 Rigid 10K 0.1mm Excludes Support Removal					
3	Bureau Print	GOPBUREAUPRINT-P1	86.85	1	86.85
NOTE: qty 13 Rigid 4000 0.1mm Excludes Support Removal					
4	Bureau Print	GOPBUREAUPRINT-P1	94.35	1	94.35
NOTE: qty 13 Tough 1500 0.1mm Excludes Support Removal					
5	Bureau Print	GOPBUREAUPRINT-P1	85.75	1	85.75
NOTE: qty 13 Tough 2000 0.1mm Excludes Support Removal					
6	Bureau Print	GOPBUREAUPRINT-P1	89.00	1	89.00
NOTE: qty 13 Grey Pro 0.1mm Excludes Support Removal					
7	Bureau Print	GOPBUREAUPRINT-P1	78.04	1	78.04
NOTE: qty 13 Flex 80A 0.1mm Excludes Support Removal					
8	Bureau Print	GOPBUREAUPRINT-P1	113.45	1	113.45
NOTE: qty 13 Elastic 50A 0.1mm Excludes Support Removal					
9	Delivery Charge	DELIVERY	6.50	1	6.50

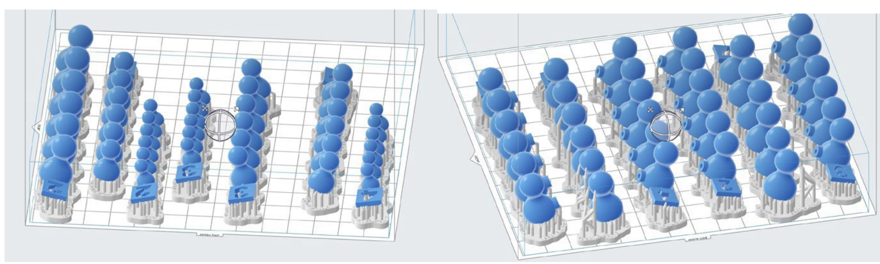
Notes: joints 12221 zip

To contact the Part Store team, please call 01765 694 000 or email partstore@additive-x.com.
To contact the Sales team, please call 01765 540 115 or email sales@additive-x.com.

Currency:	GBP
Sales Subtotal:	741.28
VAT:	148.26
Total:	**889.54**

I don't feel this is an appropriate amount to spend on tests for my study so will reduce the number of prints and materials.

I asked for images of the bed set up to see how much I can get on one bed.

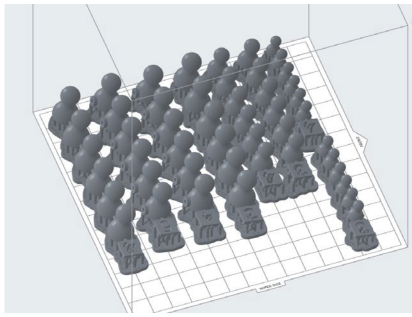


I believe that at this juncture it is worth getting the most successful tests from the SLA tests printed namely those colored green with the increased cup length V3_9/0.8/0.55 and V4_9_w/tap and those that should have worked but for some reason didn't v4_9/0.8/0.55 and V5_w/tap which will come to 8 files I may ask if there able to fit these on to one bed if not I'll drop V5_w/tap

Material wise I'd still like to try durable but perhaps one of each of the tough (2000) and rigid (10K) plus pro grey.

109.30
78.04
85.75
89.00
=362.09/2 = £181.05

Time	30mins
Date	16/3/2021

<table>
<tr><td>Activity</td><td>I have asked for reduced quotes for the above files and reduced materials I sent over a screen shot of the file set up that should hopefully allow for them to all be printed on one bed.
</td></tr>
<tr><td>Time</td><td>1 hr</td></tr>
<tr><td>Date</td><td>17/3/2021</td></tr>
<tr><td>Activity</td><td>Received update quote. Have asked Dave for advice.</td></tr>
<tr><td>image</td><td>
<table>
<tr><td colspan="6">Payment Terms: INADVANCE Shipping: DPDNEXTDAY</td></tr>
<tr><th>NO.</th><th>ITEM DESCRIPTION</th><th>SKU</th><th>PRICE</th><th>QTY.</th><th>SUBTOTAL</th></tr>
<tr><td>1</td><td>Bureau Print - Tough 2K</td><td>GOPBUREAUPRINT-P1</td><td>38.00</td><td>1</td><td>38.00</td></tr>
<tr><td colspan="6">NOTE: Prices to print, Form 2, 100 micron, excludes support removal:

Tough 2K</td></tr>
<tr><td>2</td><td>Bureau Print - Rigid 10K</td><td>GOPBUREAUPRINT-P1</td><td>37.00</td><td>1</td><td>37.00</td></tr>
<tr><td colspan="6">NOTE: Form 2, 100 micron, excludes support removal: - Rigid 10K</td></tr>
<tr><td>3</td><td>Bureau Print - Grey Pro</td><td>GOPBUREAUPRINT-P1</td><td>45.00</td><td>1</td><td>45.00</td></tr>
<tr><td colspan="6">NOTE: Form 2, 100 micron, excludes support removal: - Grey Pro</td></tr>
<tr><td>4</td><td>Delivery Charge</td><td>DELIVERY</td><td>6.50</td><td>1</td><td>6.50</td></tr>
<tr><td>5</td><td>Bureau Print - Durable</td><td>GOPBUREAUPRINT-P1</td><td>43.00</td><td>1</td><td>43.00</td></tr>
<tr><td colspan="6">NOTE: Form 2, 100 micron, excludes support removal: - Durable</td></tr>
</table>
</td></tr>
<tr><td>Date</td><td>26/3/2021</td></tr>
<tr><td>Activity</td><td>Meeting with Dave to discuss other companies, I have explained that I wish to continue to use Formlabs to keep some consistency to the machining. Discussed the difference between machines, technology, and materials. Have decided to test joints with tough only. Have requested an updated quote and payment.</td></tr>
<tr><td>Time</td><td>1hr</td></tr>
<tr><td>Date</td><td>30/3/2021</td></tr>
<tr><td>Activity</td><td>Payment sent and received waiting on tests. Then will check and try in Durable, Rigid and maybe Pro grey.</td></tr>
</table>

Date	12/4/2021
Activity	Joints arrived **Version 9_w/tap_grouped** **V4** = change of tap position with longer cup by 0.5 **V5** = change of tap position with longer cup by 0.5 and tolerance reduced by 0.5. **Version 9_grouped** **V3** = increased cup length by 0.5 **V4** = tolerance reduced by half and increased cup length by 0.5. **Version 9_grouped_0.8** **V3** = increased cup length by 0.5 **V4** = tolerance reduced by half and increased cup length by 0.5. **Version 9_grouped_0.55** **V3** = increased cup length by 0.5 **V4** = tolerance reduced by half and increased cup length by 0.5.
Date	15/4/2021
Activity	Tested joints, request new order for; Version 9_grouped_wtap_5 Version 9_goruped_4 Version 9_grouped_0.8_4 Version 9_grouped_0.55_4 Version 9_grouped_0.55_3 In durable and Rigid materials
Date	19/4/2021
Activity	Paid for order- should arrive soon.
Date	28/4/2021

Activity	Final samples arrived. Durable material proved strong and reliant in all scales. Rigid material is hard and chalky and does not go together easily. 0.55 scale also brakes. To discuss and provide a final review of all samples with Dave in the next week or so. Also establish whether it is still necessary to engage with the review committee or not.
Time	1hr

Appendices A.2 Further Analysis of Reviewed Papers from the Initial Pilot Study

Initial research into the software, technology and training required to engage with the research area was conducted to look at the potential of using 3D printing to develop a bendable limb of interlocking joints that could form an S or C shaped configuration. Literature from a variety of disciplines—including engineering, soft robotics, prosthetics, and surgical implements—was reviewed. In order to search and map the terrain, I used keywords developed from a list of parameters, as seen in the table below, to review papers from a range of disciplines. This is a more detailed analysis of those papers, as referred to in section 4.2 in chapter 4.

	A	**B**	**C**	**D**	**E**
Can the proposed arm or joint be used for the creation of a curved formational limb?	Y	Y	Y	Y	Y
Does the joint or arm hold its shape and remain rigid?	-	Y	Y	Y	Y
Is it able to be posed?	Y	Y	Y	Y	Y
Would any subsequent friction device or implement get in the way of the animator/add to the animator's workload?	N	Y	Y	Y	Y
Is the joint scalable?	Y	-	-	-	-

[*Table 4.* Papers and their suitability against the discussed parameters. Y = Yes, N = No, - = possibly/ unexplored in paper. A = "3D-printing of a non-assembly, articulated models" (Cali et al., 2012); B = "3D printing of variable stiffness hyper-redundant robotic arm" (Yang et al., 2016); C = "A novel layer jamming mechanism with tunable stiffness capability for minimally invasive surgery" (Kim et al., 2013); D = "Apparatus for temporarily engaging body tissue" (Goodman, 2003); E = "Vacuum packed particles as flexible endoscope guides with controllable rigidity" (Loeve et al., 2010)]

The first paper (A)—found by searching various databases (IEEE, UWE library, SICE and ACM) for articulation joints created using 3D printing—was a non-assembly printed joint for physical models created by Cali et al. (2012) The paper demonstrates a 3D printed ball-and-socket joint that was designed to be pre-assembled during the printing process, removing manual assembly post-print, meaning the joint can be rotated and used directly from the printer. This was achieved by using a water-soluble bridging material within the printing process, meaning that the ball and the socket are separated during the printing process by a thin layer of secondary material to stop them from fusing together. Once printed and washed, the joint is able to twist and rotate. The friction in this joint is created by having shaped features in the cross-section of the socket wall that allows the joint to be posed, twisted, and then lodged into position (Cali et al., 2012). This paper offered a potential answer to the issue of developing a joint with its own friction, as well as being assembled within the printer. It also developed a lot of testing and data regarding scaling for a 3D printing machine and what effects that has on the overall print quality, such as unwanted fusing of parts. However, the major issue when considering this for stop-motion animation purposes was that the joint, once twisted back, becomes loose again. Considering that the joint will be under the skin and clothing of a character, this could prove a difficult configuration for the animator to use on set. There is also the possibility of significant wear and tear during the animation process which could cause the joint to degrade with repeated use.

Further research into friction-free holding joint creation in the robotics field uncovered a paper by Yang et al. (B) that incorporated a multi-material ball-and-socket joint made from shape memory polymer (SMP) and acrylonitrile butadiene styrene (ABS) for use within a robotic arm. SMP is a material that becomes flexible when heated above glass transition temperatures (at 45°C) whilst ABS is a sturdy material with a heat deflection of about 86°C. This allows for the joint to be both stiff and flexible once moderate heat is applied (Yang, Y et al., 2016). The general design of the cup is of interest as there is a thorough analysis of both the motion and optimal angle for the cup's diameter to create movement and keep the ball enclosed. The use of SMP material may prove useful, and the paper suggested some novel approaches to assist in feeding SMP materials using a secondary cooling system and the nozzle head. The main disadvantage is the method for heating the filament once in the joint, in which the arm system is placed near an open oven to reach its soft state. This is an obvious health and safety issue, especially as our joint is to be manipulated by hand, over multiple shots in and around soft and flammable materials such as fabrics and sets. There is a suggestion within the paper's conclusion of using more advanced methods—such as electromagnetic induction heating—to heat the SMP material (Yang, Y et al., 2016), although this would still require extra work for the animator. There is also no mention of scalability, which would be necessary for applications with the armature of a stop-motion model.

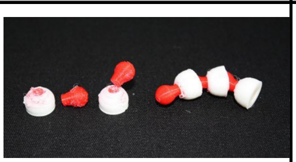
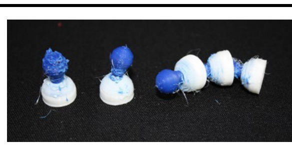
Within the medical field, a paper (C) by Yong-Jae Kim et al. (2013) explores a novel system for minimally invasive surgery that makes use of a snake-like design; the “scales” create a bendable exterior whilst an internal joint utilises interwoven flaps and a surrounding rubber membrane that is restricted through the use of an external pump, which creates a vacuum that allows the tubular mechanism to remain rigid and keep a pose. (2013:1031–1042). Although this joint has some desirable attributes, such as adjustable stiffness, it still relies on an external mechanism—including a pump to create the vacuum that provides rigidity—so would not be ideal for use in a stop-motion armature due to the inconvenience of having to accommodate these extra elements in the system. The scalability of the joint system was not investigated within the paper; this was probably not considered to be an issue since to serve its primary purpose the device would be required to fit inside the body cavity. As stated, due to the requirement of the pump and other additional mechanical elements in the system, I consider this to have limited potential within stop-motion animation.

A patent for a “temporary engagement apparatus to stabilise body tissue”, invented by Jack Goodman et al. (D) was submitted in 2002. The patent describes a surgical implement that makes use of multiple cups with holes in their centres to allow for a tensioning cable that is used to lock off the arm and suction pods apparatus at the other end. The tensioning cable is then locked, causing the links of the cups to hold against each other and stay in place. This is aided by the flared shape of the internal hole generating a sharp angle that, when created along with multiple cups, results in a smooth curve (Goodman, 2003). This idea of a free moving system of cups that can be posed before locking may work within the framework of stop-motion. The elements to trial from this invention would be its scalability and simplification; this device is meant for highly complex surgeries and has a stiff clamping mechanism at its base as well as suction paddles or pods to help engage with the organ or tissue, which would be unnecessary for the intended use in animation.

The final paper (E) describes a particle packed vacuum tube or shaft created by Loeve et al., which uses orbs and gravel of various hardness for an endoscopy arm. The system allows for flex, posing and solid rigidity to enable the tube to be inserted into the body. The shaft is comprised of a foil tube, filled with particles or orbs, that when a vacuum is applied becomes rigid due to atmospheric pressure (Loeve, 2010). A lot of detail was provided regarding the particle materials (such as glass and acrylic), the difference between spheres and granules, and what effect these variables had on the stiffness of the shaft before and after the vacuum was applied. On reflection, the viability of this method as a tool in my own research is limited due to the scale at which this arm would be capable of being created without losing its structure. The vacuum would also be obstructive to the animator and add complexity to the animating process.

These papers were used as a foundation to construct and explore my own 3D printed joint design, which can be seen in chapter 4 of this thesis.

Appendices A.3 Material Analysis Log

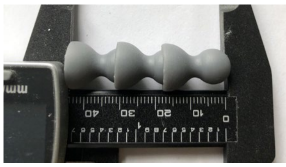
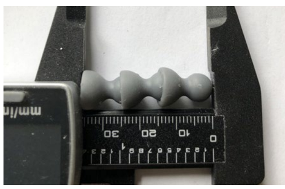
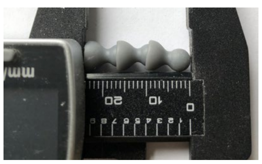
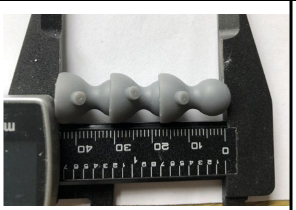
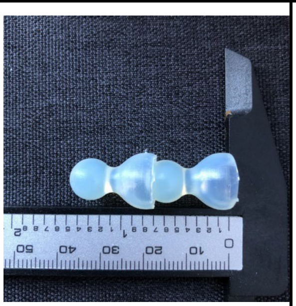
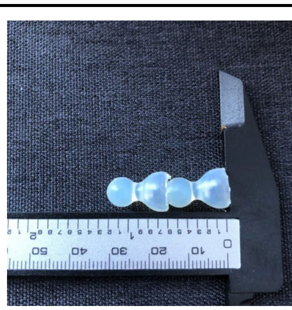
MATERIAL/ PRINTER	IMAGE	VERSION/ SCALE	ANALYSIS	RESULT/ NEXT STEP
FDM				
Polyflex/ RoboxPro		Version 1	Highly useful, creates a tight fit and allows freedom of movement. Risk of tearing at the neck. Test prints on the side warranted good strength but reduced the quality of the joint overall. Try reducing cup angle to increase movement.	Try a flexible material with a higher finish/quality. Reduce the cup.
PLA White-Red/ RoboxPro		Version 3	Too brittle and coarse, difficult to create a tight fit that will also snap together when used by itself.	Try flexible materials.
ABS blue/ RoboxPro		Version 3	Too brittle and coarse, difficult to create a tight fit that will also snap together when used by itself.	Try flexible materials.
NinjaFlex/ Creator Pro Flashforge		Version 3	Reduced cup angle adds movement but reduces hold. Slightly higher quality finish from machine/material.	Move on to mixed material printing.
Mixed FDM				
Ball PLA (red) Socket Flex/ RoboxPro		Version 4.2	High likelihood of snap-in neck. No definable difference between ABS and PLA.	Redesign suggested incorporating the cup into the solid material, as seen with version 4.3
Ball ABS (blue) Socket Flex/ RoboxPro		Version 4.2	High likelihood of snap-in neck. No definable difference between ABS and PLA.	Redesign suggested to incorporate cup into the solid material,

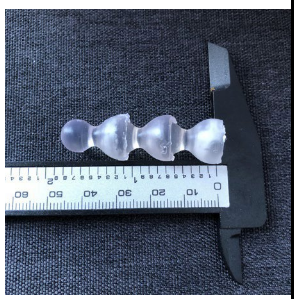
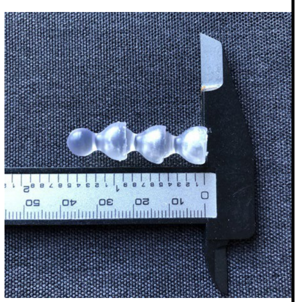
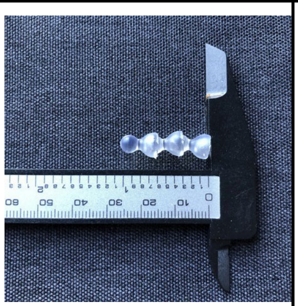
<table>
<tr><td></td><td></td><td></td><td></td><td>as seen in version 4.3</td></tr>
<tr><td>Ball Flex, Socket PLA (red)/ Robox Pro</td><td></td><td>Version 4.2</td><td>No connection possible.</td><td>No further action.</td></tr>
<tr><td>Ball PLA (red) Socket Flex/ RoboxPro</td><td></td><td>Version 4.3</td><td>Although strong externally, the strength of hold when put into place is weak.

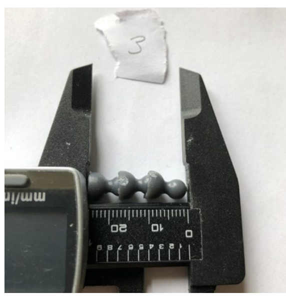
No definable difference between ABS and PLA.</td><td>Look into other printing technologies/ materials to aid in strength and scale studies.</td></tr>
<tr><td>Ball ABS (blue) Socket Flex/ RoboxPro</td><td></td><td>Version 4.3</td><td>Although strong externally, the strength of hold when put into place is weak.

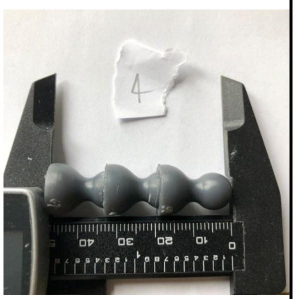
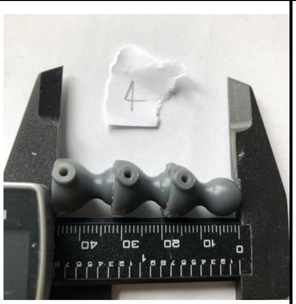
No definable difference between ABS and PLA.</td><td>Look into other printing technologies/ materials to aid in strength and scale studies.</td></tr>
<tr><td>FDM Conclusion</td><td colspan="4">FDM is one of the most prevalent 3D printing technologies due to its simplicity, affordability, accessibility, and adaptability. It has provided some interesting results, especially when considering the design and the ability to mix materials. There are drawbacks, however. Reducing scale beyond these tests is tricky due to the quality and practical considerations of the manufacturing process. Working at a larger scale may prove useful for more mechanical parts. I have seen good use of this for winders, rigs, and other mechanical elements of stop-motion animation construction, however at the scale range used for armature construction FDM has limited benefits. Material range and strength is another consideration. Although new materials are becoming available - different hot ends, nozzles and machines are also required. It is the overall structure of the build that lets the use of this technology and these materials down for this specific type of joint design, however, as it creates fracture points, and the overall quality of the prints often create a reduced performance.

Findings from these tests have highlighted two considerations for this study going forward. The design of the joint, although simple, must constantly be re-addressed and altered to work for different types of technology and materials. Changes in tolerances, layer heights and supports are all things that are addressed in the design stage and must be documented and discussed throughout, as a straightforward analysis and comparison of one version of the design for all materials is not possible. Access to various technologies is also an issue, although the CFPR is equipped with many FDM machines and towards the end of my study, an SLA machine was purchased. As these machines are used by multiple people for various studies, changing the materials between prints is hard and often not possible. Using bureau services</td></tr>
</table>

	has been determined to be the best next step but this too has its own problems that will be discussed going forward.			
SLA-formlabs				
Grey Resin/ Formlab		Version 9	Snaps together well but has little to no hold, can neither hold itself aloft nor take any weight.	
Grey Resin/ Formlab		Version9_ 0.8	Snaps together well, holds slightly better at this scale, can hold itself aloft for a while but wouldn't carry much weight.	
Grey Resin/ Formlab		Version 9_0.55	Snaps together well but has little hold and will come apart easily if rotated much. Can hold itself aloft but unable to carry any weight.	
Grey Resin/ Formlab		Version 9_w/tap	Snaps together but has a very loose hold, can neither hold itself aloft nor take any weight. Tap holes too small.	
Durable/ Formlab		Version9_ flex	Little to no flex. Cannot snap together by hand. Feels robust so would be good for other applications where stability is required more. Perhaps a reduced tolerance would create a tighter fit.	
Durable/ Formlab		Version9_ flex_0.8	Little to no flex. Cannot snap together by hand. Scale makes no difference.	

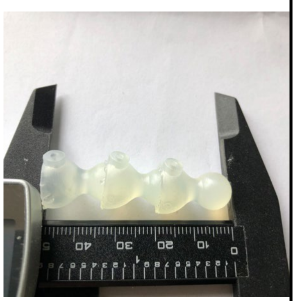
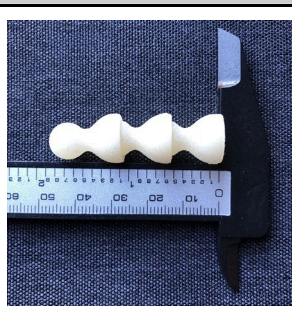
Durable/ Formlab		Version9_ flex_0.55	Little to no flex. Cannot snap together by hand. Scale makes no difference.	
Flexible/ Formlab		Version9_ flex	High level of flex fits together well. Holds in place nicely unless overexerted and then will pop out. Works at full scale. Perhaps elongating the cup would help but would reduce overall movement.	
Flexible/ Formlab		Version9_ flex_0.8	High level of flex fits together well. Holds in place nicely unless overextended, then will pop out of place. Works but less hold at 0.8 scales. Perhaps similar elongating of the cup would help but would reduce overall movement.	
Flexible/ Formlab		Version9_ flex_0.55	High level of flexibility. Does sit together but feel if moved too sharply will not hold well. An elongating cup would help in keeping parts together but would reduce overall movement.	
I have been impressed with the materials and feel they may have application in further projects, but for this specific joint design they lack either the strength or ability to snap together or retain hold through movement. The angle of the cup is too loose for the flexible material and too closed for the ridged. At this stage, altered designs were used due to results uncovered through tests using the SLS printing process, which was being developed in tandem.				

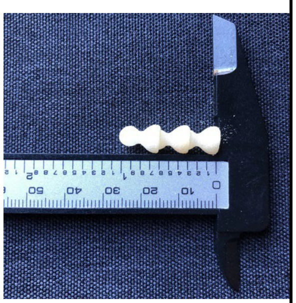
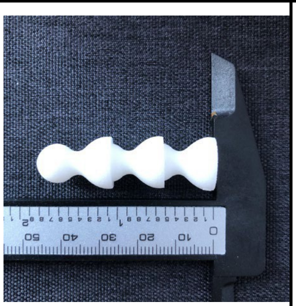
Tough 2K/ Formlab		9_grouped _V3	Strong connection with good, stable hold. Some slight looseness to rotation on each individual part.	Will use V3 version of 9 grouped going forward
Tough 2K/ Formlab		9_grouped _0.8_V3	Connects well, but loose overall connection. Holds together well but the stability of the system is not good enough, very loose rotation on individual parts.	We will use V3 version of 9_0.8 grouped going forward
Tough 2K/ Formlab		9_grouped _0.55_V3	Connects well with some looseness but overall, a strong hold. Similar loose rotation but overall good. Wouldn't hold aloft for long and would not hold much weight.	Will use version V3 and V4 for the 9_0.55 grouped system going forward, as no discernible difference was found in this material. This smallest scale version of the system is most likely to have minor changes affect its functionality.
Tough 2K/ Formlab		9_grouped _V4	Strong connection with a stronger hold, very stable, nice solid rotation on individual parts, doesn’t come apart easily. Good result.	Will use version V3 and V4 for the 9_0.55 grouped system going forward, as no discernible difference was found in this material.

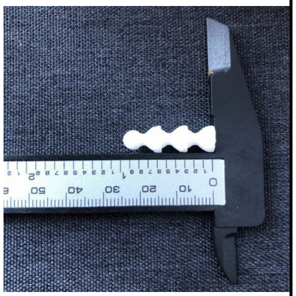
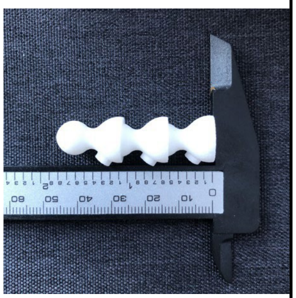
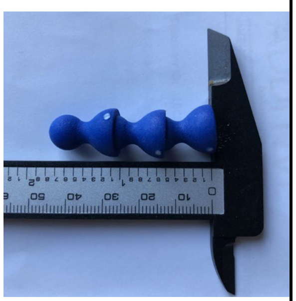
				This smallest scale version of the system is most likely to have minor changes affect its functionality.
Tough 2K/ Formlab		9_grouped _0.8_V4	Good connection holds together well with reasonable rotation of individual parts. Not much better than 0.8_V3, slightly better overall hold and doesn't come apart as easily.	
Tough 2K/ Formlab		9_grouped _0.55_V4	Very similar to 0.55V3, the design doesn't seem to offer any greater hold or stability but works fine. Neither hold aloft nor would hold much weight.	
Tough 2K/ Formlab		9_grouped _w/tap_V4	Good, strong hold once tapped, and grub screw added. Is able to maintain a solid position with no movement. The slight flex in the resin creates a good level of strength and does not break down under the additional pressure. Will of course still break down over time through wear but happy with results.	
Tough 2K/ Formlab		9_grouped _w/tap_V5	Good, strong hold once tapped, and an added grub screw is able to maintain a solid position with no movement. The slight flex in the resin creates a good level of strength and does not break down under the	Will use V5 of the taped joint going forward.

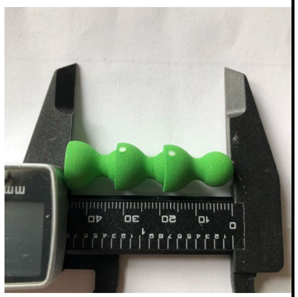
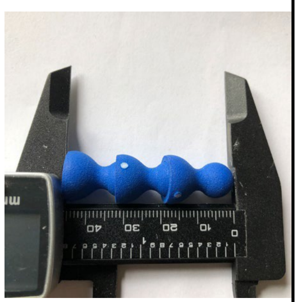
			additional pressure. Will of course still break down over time through wear but happy with results. Holds overall more efficiently in this version.	
Tough 2K/ Formlab		9_grouped_w/tap_V5	Good, strong hold once tapped, and an added grub screw is able to maintain a solid position with no movement. The slight elasticity to resin creates a good overall strength, the material doesn't feel as if it is going to break under the additional pressure. Will of course still break down over time through wear but happy with results. Slightly stronger hold pre-tapping than v4.	
Rigid 10K/ Formlab		9_grouped_V3	Horrible overall, chalky feel to the material, no connection possible.	
Rigid 10K/ Formlab		9_grouped_0.8_V3	Horrible overall, chalky feel to the material, no connection possible.	

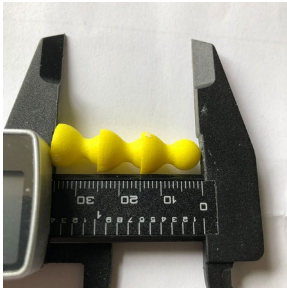
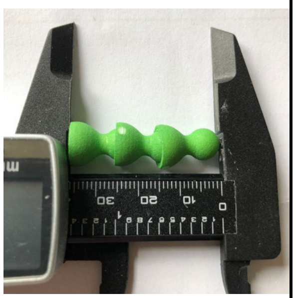
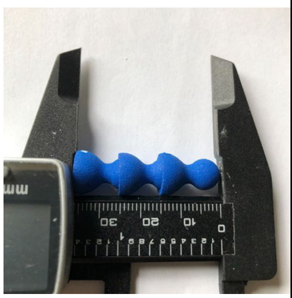
Rigid 10K/ Formlab		9_grouped _0.55_V4	Horrible overall, chalky feel to the material, no connection possible. Also, breakages occurred	
Rigid 10K/ Formlab		9_grouped _0.55_V3	Horrible overall, chalky feel to the material, no connection possible. When forced, the cup broke revealing the material to be brittle.	
Rigid 10K/ Formlab		9_grouped _w/tap_V5	Horrible overall, chalky feel to the material, no connection possible.	
Durable/ Formlab		9_grouped _V4	Connects easily but doesn't have a great hold. Rotation of individual parts is good, and it can hold itself aloft but would take minimal weight.	
Durable/ Formlab		9_grouped _0.8_V4	Connects easily and has a slightly better hold than 9_grouped but still comes apart easily. Can hold itself aloft but also would take the minimal weight. Good rotation of individual parts.	

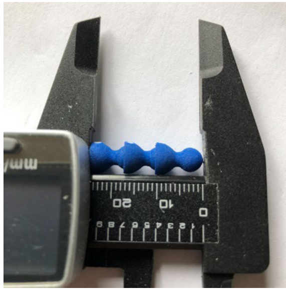
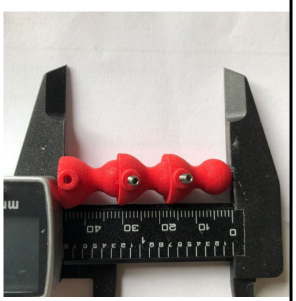
Durable/ Formlab		9_grouped _0.55_V4	Connects well but holds slightly less tightly than with the Tough material. Good rotation holds aloft and would take the minimal weight. Slightly better than 0.55_v3	
Durable/ Formlab		9_grouped _0.55_V3	Connects well but holds slightly less tightly than with the Tough material. Good rotation holds aloft and would take minimal additional weight.	
Durable/ Formlab		9_grouped _w/tap_V5	Connects well but lacks strength in the hold. Once tapped creates a reasonable hold but still reasonably easy to move.	
SLA Conclusion	The range and scope of material available with SLA printing is much larger than any of the other technologies. A reasonable level of success has been found in most materials tested during the study, the most successful of which was with the Tough material for the particular joint being tested. This snapped together well, with reasonable hold, and was able to stay aloft. It would have minimal weight-bearing capacity but that is an issue with the design itself. Durable and flexible materials also offer some interesting results. In future if a need for tight fits for moveable parts is required then the flexible material may prove beneficial. Its translucent quality may also have uses. The flexibility of the material may also be applicable for mould-making or objects designed to be skinned or have other, stronger forms of joint housed within.			
SLS				
PEBA FLEX		Version9_ flex	Dense, flexible material - with fine, dusty surface texture. Snaps together well and remains secure, poseable with a good level of movement and hold. Once again, it will come out of the socket if	

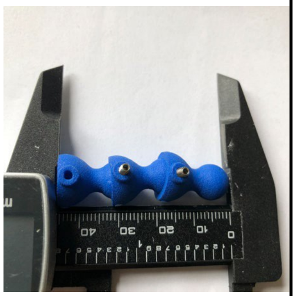
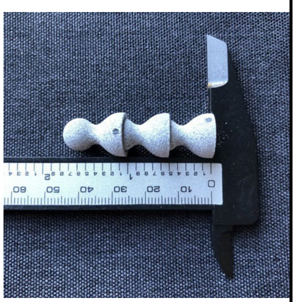
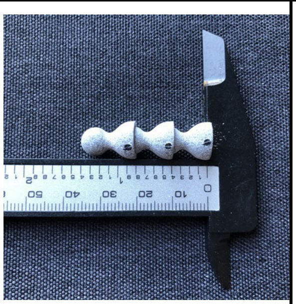
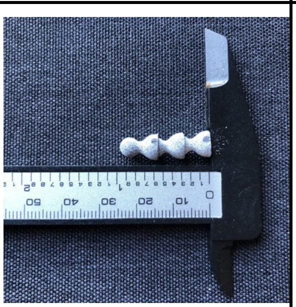
			overextended. Elongating the cup would potentially add strength to the hold but may prove problematic to snap together.	
PEBA FLEX		Version9_ flex_0.8	Dense, flexible material - with fine, dusty surface texture. Snaps together well and remains secure, poseable, with a good level of movement and hold. Once again, it will come out of the socket if overextended. 0.8 scale works to a similar degree at full scale. Elongating the cup would potentially add strength to the hold but may prove problematic to snap together.	
PEBA FLEX		Version9_ flex_0.55	Dense, flexible material - with fine, dusty surface texture. Snaps together but comes apart too easily, not a brilliant function. Would need to increase cup length but this too would reduce movement.	
PA2200 Nylon		Version9	White with a slight powder texture to the surface. Brilliant results. Snaps together and holds well. May struggle to keep aloft.	
PA2200 Nylon		Version9_ 0.8	White with a slight powder texture to the surface. For some reason, a lot looser - not sure why this would be. Would benefit from increasing cup length.	

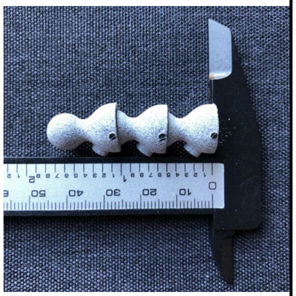
PA2200 Nylon		Version9_ 0.55	White with a slight powder texture to the surface. Snaps together but doesn't stay. This scale would benefit from a longer cup length.	
PA2200 Nylon		full_w:tap2	White with a slight powder texture to the surface. Snaps together well straight from the printer. The angle of the tap is incorrect and causes the joint to push apart rather than secure its position. This will need to be changed in design.	Series of iterative changes created to tap position to test materials.
PA2200 Nylon /polished and died (blue)		Version9	As these are polished, I had them dyed to make them easily identifiable. They snap together, but there is too much movement, which is also an indicator of what may happen once the unpolished versions are moved more, and the uncured powder is smoothed away over time.	
At this stage small iterative changes were made to the designs at different scales to identify the best possible movement moving forward [see appendix A.1 for details]				
PA2200 Nylon/ died (yellow)		9_grouped _V2	Far more robust hold, tight ‘snap/pop’ fit, with a good range of movement, motion, and rotation. Vastly improved from the last batch at this scale, however, will still come apart if rotated too far.	

PA2200 Nylon/ Died (green)		9_grouped_V3	Great hold, slightly looser movement than with V2. Doesn't come apart as easily, the rotational difference is minute between V3 and V2.	V3 has the best movement, hold and strength of the various versions of the design. Moving forward, this will be tested in more SLA materials that have similar tolerance parameters.
PA2200 Nylon/ Died (blue)		9_grouped_V4	Rather disappointing as this has the worst hold of the three. Fits together well and rotation is good, but it doesn't stay aloft like V2 and V3. This is strange as, at worst, it should have been too tight by combining the attributes of both models. Either there has been a slight alteration in the printing process, or the file is incorrect.	Having reviewed the files and checked the tolerance between the ball and socket V2 has a space of 0.05 and V4 has a space of 0.04, which should have created a slightly tighter fit if anything. This can be put down to a minor inconsistency in printing. Due to this inconstancy, it warrants further testing in the next stages of SLA material along with V3 samples.

PA2200 Nylon/ died (yellow)		9_grouped _0.8_V2	Far more robust hold, tight ‘snap/pop’ fit, with a good range of movement, motion, and rotation. Vastly improved from the last batch at this scale, however, will still come apart if rotated too far. Slightly better hold than Version 9_grouped_V2	
PA2200 Nylon/ Died (green)		9_grouped _0.8_V3	Very snug fit, snaps together well and rotational hold is good. You would have to apply quite a lot of force to make it come apart. Overall better performance than Version 9_grouped_0.8_V2	V3 and V4 will be tested in further SLA material samples.
PA2200 Nylon/ died (blue)		9_grouped _0.8_V4	Snug fit, snaps together well and rotational holds are also good, if not a little looser than V3. I still feel that over time the tensioning may decrease, leaving the system flaccid and unusable.	V3 and V4 will be tested in further SLA material samples.
PA2200 Nylon/ Died (yellow)		9_grouped _0.55_V2	Won’t really snap together and if it does it comes apart if moved.	
PA2200 Nylon/ Died (green)		9_grouped _0.55_V3	Snaps together and some rotation possible but comes apart easily.	V3 and V4 will be tested in further SLA material samples.

PA2200 Nylon/ Died (blue)		9_grouped _0.55_V4	By far the best result but will still come apart easily if rotated sharply too far.	V3 and V4 will be tested in further SLA material samples.
PA2200 Nylon/ Died (yellow)		9_grouped _w/tap_V2	Snaps together well with reasonable hold. After tapping with M2.5 x 6 grub screw, once tightened still comes loose - the angle of tap is insufficient. Additional pressure from the screw is distorting the cups and may prove to be a problem over time.	
PA2200 Nylon/ Died (red)		9_grouped _w/tap_V3	After tapping with M2.5 x 6 grub screw, once tightened still comes loose - the angle of the tap is insufficient.	
PA2200 Nylon/ Died (green)		9_grouped _w/tap_V4	Good, tight fit on the assembly, snaps together well. The addition of the grub screw allows for complete rigid hold of the joint. Tolerance can be altered to create a tighter fit, however this raises issues with scraping the internal ball as it is still only nylon and potential concerns remain due to access, depending on where and how the joint was to be used.	V4 and V5 will be tested in further SLA material samples.

PA2200 Nylon/ died (blue)		9_grouped _w/tap_V5	Similar functionality to V4, slightly looser clicking together before addition of grub screw. Creates a tight hold once added, can be priced apart once fitted, but causes scraping and damage to the internal ball.	V4 and V5 will be tested in further SLA material samples.
SLS Conclusion	SLS has offered good results in terms of accuracy to the original design, but some slight inconstancy has been found in the print process as seen in the secondary samples for 9_V3, 9_0.8_V3, 9_0.55_V3, 9_w/tap_V5 (all died blue). SLS printing offers a good surface finish that can be increased with polishing. Its ability to be colored post-print may also be of interest. In regard to functionality for moveable parts, it has a reasonable strength (tensile strength 45 + 3).			
MJF				
Nylon		Version9	Grey powder finish. Goes together but no snap, too loose, tolerance too high. Seems very strong, with little to no bend when squeezed.	
Nylon		Version9_ 0.8	Grey powder finish. Goes together but no snap. Holds slightly better than full scale due to tolerance reduction but still too loose, tolerance too high. Seems very strong, with little to no bend when squeezed.	
Nylon		Version9_ 0.55	Grey powder finish. Goes together but no snap. Holds slightly better than full scale and 0.8 scale due to tolerance reduction but still too loose, tolerance too high. Some flex in material as the scale is decreased. Seems very strong, with little to no	

			bend when squeezed.	
Nylon		full_w:tap2	Grey powder finish. Goes together but no snap, too loose, tolerance too high. Easy to tap, but the same issue regarding tap angle as with SLS Nylon full_w:tap 2, tap pushes joint apart.	As the overall results are very similar between MJF and SLS in terms of tolerances, no further testing is required as a comparable result will be possible from the additional SLS tap changes.
Nylon /polished and died (black)		Version9	As these are polished, I had them dyed to make them easily identifiable. They don't snap together as there is too much space between cup and ball which indicates that, as the versions are moved further, the uncured surface powder will be smoothed away over time, potentially causing a reduction in function.	
MJF Conclusion	Similar results to those found with SLS but with the additional strength of MJF printed nylon that offers a tensile strength of 48 MPa/6960. Having to process the polished finish in this material is a possible consideration to how the joining may become looser over time due to wearing a way of uncured material on the surface layer. This would need to be considered if the material was to be used in later projects.			
Loss cast				

Brass		Version9_ w:tap	Created using SLA wax resin, and loss cast process. Heavy and uneven shapes. Used tap as a pour hole. Does not snap together due to uneven build and internal lip on the cup. Would need a significant post-process, including filing, milling, and polishing.	No further actions.
Lost cast conclusion	This technique is of little use unless you have the skill and access to the machinery to do it yourself in order to try and reduce flaws. It is unlikely to be useful for functional parts but may prove useful for decorative elements if a basic form and material was important, however it would still potentially require a lot of post-processing.			

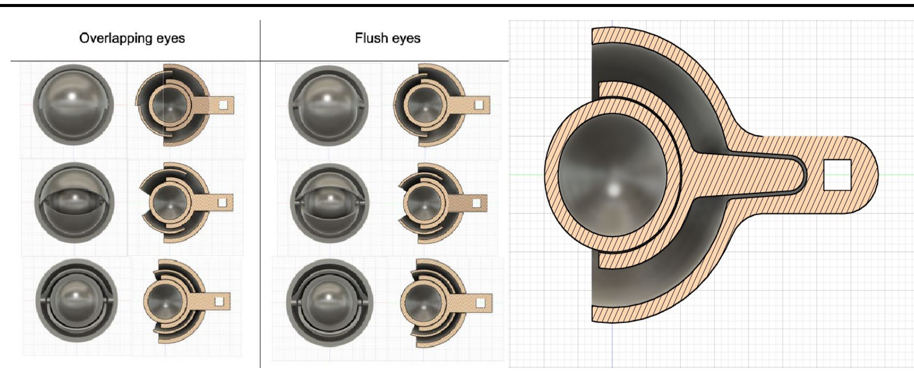
Appendices B.1 – Project Log: Auteur filmmaker eye mechanism – SHACKLE.

Project Name	Eye Mechanism - Shackles
Participants	Ainslie Henderson, Laura-Beth Cowley
Date	10/1/2020
Activity	Initial conversation about projects after intial letter of intent sent on 7/11/2019. Waiting to hear about BAFTA funding bids.
Time	1hr
Date	11- 14/2/2020
Activity	Email correspondence: after being sent the initial STL Blender design, I asked a few questions about the design and scale of the puppet, the eyeballs will be roughly 20mm. Ainslie responded that he imagines the puppet to be about 40cm tall with a wide set head, he imagines the pole to allow him to adjust the eye rig to suit any puppet and send the below initial designs. He intends to needle felt the body of the puppet.
Date	18/2/2020
Activity	Initial test of Ainslie's joint design. Notes sent to Ainslie : ● It printed relatively well. Printed with PLA (sorry we didn't have white in at the moment). ● I'd say there are some spots that are a little weak such as the support rod and the parts that hold the eye in place. ● Also, due to the way the model was created, the object isn't able to be printed fully solid which I think would help the overall strength. ● Due to tolerance the rod doesn't fit in the base of the rig, but I think it would be useful to increase the size of this whole and perhaps use a k+s brass square tube instead for sturdiness.
Time	2-3hrs prep print and printing
Image	 

Date	23/3/2020
Activity	Correspondence/email: in response to my email on the 6/3/2020, confirmation that funding has been allocated but 3D print use is much reduced now only focused on eye mechanics, COVID-19 may cause delays.
Date	6/5/2020
Activity	Zoom call - discuss changes to model, little imperfections, and issues. - He now requires eyelids, so the model has changed - The scale of model is wrong due to a save/render-discussed ways of fixing this - FDM printing creating error possibly due to minor deformities in the file or support removal - Discussed moving over to SLA printer for quality of print- need to raise questions about tolerance and fragile print quality as well as colour - Discussed adding holes to model to allow for needle felting - I am going to create a version in fusion - Wants eyelids to meet rather than slide over one another - Also potentially extend back of eye holder
Time	1hr
Links	CG model: https://www.shapeways.com/product/MB2FXGMZ6/20mm-eye-gimble Akira head: https://www.upuno.com/shop/body-parts/akira-101-blank-head/ Akira video: https://www.youtube.com/watch?v=oJ13yS8bPUI Julian Clarke: https://www.stopmotionshop.com/3d-printed-puppet-head---simple-484-p.asp
Date	7/5/2020
Activity	Redesign in fusion 360
Time	2-3hr
Date	8/5/2020
Activity	Correspondence via Whatsapp -discuss previous design/print floors -discuss other designs mentioned in previous meeting -discuss new design involving two interlocking CPAs with the eyelids in between
Time	Throughout day 1-2 hrs
Date	11/5/2020

Activity	Continue previous design
Time	1hr
Date	11/5/2020
Activity	Zoom meeting: -discuss the attributes and benefits of fusion -discuss current design -discuss new 2 cup system for eye rig -discussing flexy material as internal cup w/connected stalk and bracket -discuss terminology for element of design (bracket, socket, inner and outer cup, lids, stick/stalk) -discuss tolerance and space for felted material -Discuss the use of lubricant inside eye cup (Vaseline, KY jelly, tacky wax) -Ainslie remembered the reason for overlapping eyes in his first design was to create an overlapping squinting eye, like that of a camera lens, but with the original bracket system this would still remain mechanical/shutter-like - Laura-to look into how to make this work-perhaps curved eyelids. -also Laura to start looking at printing options in colour, material and cost
Time	1-2 hr
Date	14/5/2020
Activity	Modeling eye rigs as described in the last meeting. Replicated versions listed below; - Ainlsie_eye_rig > eye v2_1_meet - Ainlsie_eye_rig > eye v2_1_meet_2 - Ainlsie_eye_rig > eye v2_2_overlap Established naming conventions **Meet** = eyelids meet together flush [shutter like] **Overlap** = eyelids overlap to be used for slitted eye **Cup** = outer eye cup to protect lids **Lid** = bottom/top eyelids **Socket** = cup around eyeball **Bracket** = v1 central rod run from cup/socket to attach eyes to **Clips** = v2 rods that clip into socket/cup from eyelid **Stalk**= final part of design run from socket through cup to allow the eye to be connected to the puppet and also allow for cup and socket to attach together. Created joint animations to figure out how they would work in real world set up. eye v2_1_meet: ● upper_lid > clips out to cup ● bottom_lid> clip in to socket ● Not at centre = misaligned rotation of lids

	eye v2_1_meet_2 ● upper_lid > clips out to cup ● bottom_lid> clips out to cup ● Not at centre = misaligned rotation of lids eye v2_2_overlap ● upper_lid > clips out to cup ● bottom_lid> clip in to socket ● Clips Centred = successful rotation of lids ● Need to include cut to front of eyelid to allow for slit eye NEXT STEP: Complete above designs and create eye v2_1_meet_3 with centralised clips.
Time	4 hrs
Date	18/5/2020
Activity	Completed design: v2_1_meet_3 Edited v2_2_overlap: to include slitted eyes. Started and finished: ● v2_1_meet_4 (different clip style) ● v2_1_meet_4 (different clip style) ● v4 (combination of v1 and v2) Started Researching Bureau's [see Bureau Service List below] Next Steps - arrange meetings with Ainslie, Tom, Dave - Research bureaus and material tolerances.
Time	6 hrs modeling | 1hr research list
Date	19/5/2020
Activity	Researched Bureau List and Meeting 12-1pm Ainslie. Discussed; Designs: v4 / v2_1_meet_5 / v2_2_overlap Decided to go with v2_1_meet_5 - and try and incorporate a pair overlapping/slitted eyes into the design - Make sure tolerances abide by Formlab requirements - Increase space between cup and socket to allow for overlapping eye - Increase clip size - animate/change rotation point to show how eyelids will move Friday - have new design ready to print

	Cost out based on v2_1_meet_5 with any resin printing service Email- Fabio about Formlab ✓ Email- Tom about design check and rotation ✓ Created new design based on combination of v2_1_meet_5 & v2_2_overlap now labeled v5
Time	Research list - 3 hrs | Modeling - 3.5 hrs
Date	20/5/2020
Activity	Final tweaks to v5 Documented variations of eyelids open, closed, half open. Meeting with Ainslie 12PM to discuss finalised design and any revisions; - Discussed fluting the stork out from the back of the socket through cup to help make sure it is accurately placed when put together post print After meeting Whatsapp note: - Included stork on the outer cup with shorten stalk from socket inside. For post-print gluing and strengthening. Emailed Fabio STL files and arranged a meeting for 4pm. Meeting notes; - Arranged files in preform (Formlab slicer) discussed rotation to get best quality for socket, cups and lids - Will be printed overnight for collection tomorrow
Time	Design - 2hrs | meeting's - 2hrs
images	 [New Stalk Design]
Date	21/5/2020
Activity	Designed eyeballs based on Ainslie's original design 1hr

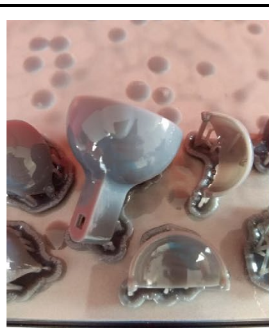
<table>
<tr><td></td><td>Collected test print. Evaluation; 30mins

- Print quality outstanding
- Eyelids perfect - may benefit with some embossing in design to help aid connection once printed
- Clips - perfect set at 0.1 tol
- Eye fits well once in can’t easily remove due to socket being fixed resin
- Slight increase in eye > socket tolerance may help move easier but paid off again good tight fit.
- Meeting edges of eyelids and eyeball could benefit from tiny amount of wet & dry sanding to get rid of last bits of support
- Stalk a little wobbly - reduce tolerance, perhaps removal bevel
- Angle on lid may benefit with a slight increase to stop them falling back into the cup
- Bottom eyelids- droop

Meeting with Ainslie to discuss changes; 30min

- Inner clips- bevel slightly to try and stop flop ✓ [beveled holes instead]
- Discussed adding felt to inside of some eyelids to have more control
- Reduce stalk socket tolerance 0.2 ✓
- Try a new design setting the eyeball up as 10mm rather than 20mm
- Post - eye to Ainslie tomorrow
- New eyeballs-fine
- Contact print service for quote once original design edited
Redesign for adjustments 2hr

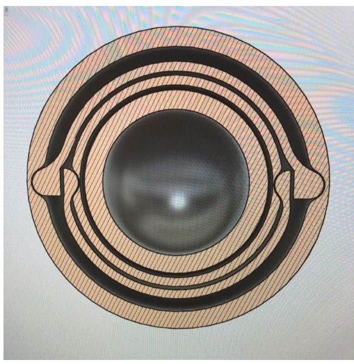
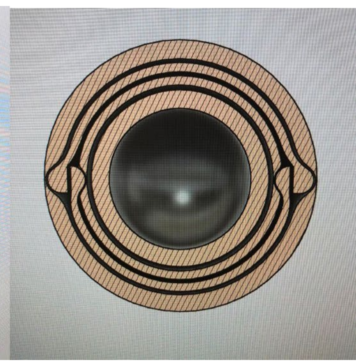
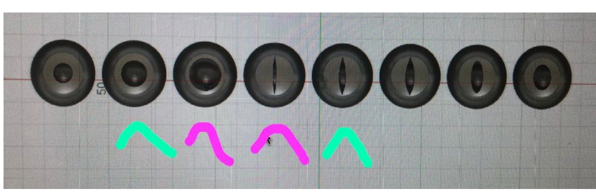
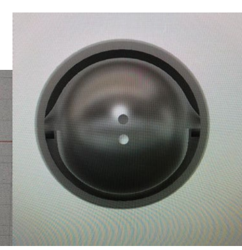
- Changed stalk tolerance- reduced bevel on entry to cup stalk
- Added bevel to socket clip recess

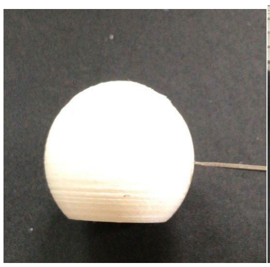
Start 50% scale design 2hrs</td></tr>
<tr><td>Time</td><td>6hrs</td></tr>
<tr><td>images</td><td>  </td></tr>
<tr><td>Date</td><td>22/5/2020</td></tr>
<tr><td>Activity</td><td>Post model to Ainslie</td></tr>
</table>

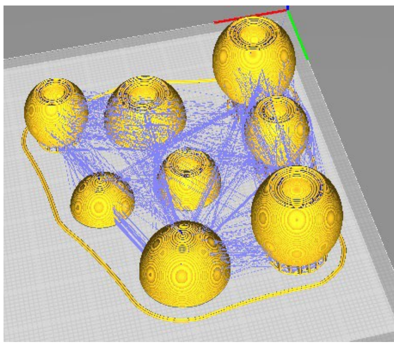
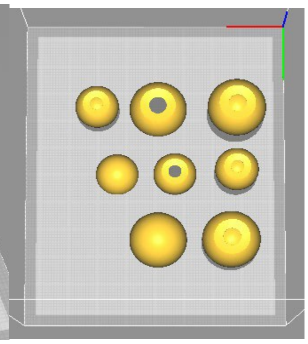
	Finish 50% scale redesign and 50% eyes 3hrs Contact GoPrint3D for print time and cost Final check with Ainslie; ● Two of eye each eye set- v5 Larger & v6 Small ○ Socket clear elastic and White resin everything else ● Two of each set of eyeballs - large - small - in white resin ○ 4 of eyeball 1,2,3 small and large Send over STL files 1hr
Time	4hrs
Date	26/5/2020
Activity	Confirmation via Whatsapp: Ainslie received eye rig -A: Delighted with result -A: Offer of payment for services and credit on film -L: Said I will ask about ethics on payment for case study from the researcher's perspective but happy to be credited in film. -L: Will chase up printers tomorrow
Date	27/5/2020
Activity	Contacted GoPrint3D to chase up a quote - reply: will let us know by the end of day or tomorrow.
Time	10 mins
Date	1/6/2020
Activity	Contacted GoPrint3D to chase up a quote - reply: STL files still with engineer- will get back to us soon. Ainslie sent over the script, asked about potentially looking at other printing services and asked about payment for service rendered by researchers again. Reply: unsure what's the hold up with GoPrint3D, has started looking for other services, will read script today, would like to discuss payment once quote has been realised as unsure how costly it will be. Read script: the eyes feature quite heavily and are clearly an important aspect to both the puppets and the narrative - this is good. Hugely impressive story with significance to the artist's condition, nature, and loyalty. Ainslie asked for feedback/clarity on the films message as an observer.
Time	1hr

Date	3/6/2020
Activity	Contacted other bureaus as heard nothing back from GoPrint3d: Contacted CREAT3D - have received quote for full amount of pieces £286.80 (w/TAX) Contacted Bristol- HOBS- just to see if they have the printers and material on offer Discussed options with Ainslie via WhatsApp. - Discussed getting a test of the smaller piece with mix material and two larger eyeballs printed - Requested quote form Laser Lines. Estimate: £39.76 - Quote received £90.48 waiting for further quotes to compare pricing Asked CREAT3D Simon Chandler about pricing convention. As there must be quite a large base rate of costing based around set up and staffing per job rather than simply by material.
Time	2 hrs
Date	4/6/2020
Activity	Contacted Laser Lines for quote; • offered free sample so request Larger eye socket in clear elastic - should arrive next week with Ainslie • requested quote for full amount • Request quote for test prints GoPrint 3D quote - full amount of pieces £245.40 - asked for amendment due to erroneous file and clarification of quantity - asked for quote for test sample
Time	1hr (all day weighting between correspondence)
Date	5/6/202
Activity	Laser lines; Will give quote on Monday GoPrint3D; Decided to go ahead with test quote trial Ainslie has paid awaiting confirmation Discussed have a test of the smaller scale printed by Fabio
Time	2hrs

Date	8/6/2020
Activity	Collected test print form Fabio; Scale has arisen as an issue to do with strength of fit Stalk internal socket may have some additional cured resin which has created extremely tight fit 10mm eye has filled with resin and closed detail this was an extremely small scale test exit hole of 0.5mm
Time	1hr
Date	9/6/2020
Activity	Chased up laser lines for sample and quote; Sample hasn't been sent They seem unable to provide quote We have decided to not proceed with them as viable providers
Time	30mins
Date	10/6/2020
Activity	WhatsApp conversation with Ainslie Ainslie has created felting test [see video's] Suggest adding hole to center of lids to help with animation Possibly reduce space between eyelids and eyeballs currently 1.5mm Eyeball sanded/against felt create good movement possibly don't need elastic Grey resin may also be fine - but what about eyes?
Time	20mins
Video	00000311-VIDEO-2020-06-10-16-23-04 00000314-VIDEO-2020-06-10-18-38-53
Date	11/6/2020
Activity	● Create version 5_2 reducing tolerances - 0.8mm off full size and between lid and eyeball ● Emailed Go Print 3D chase up print test ● Created version 5_3 with reduced circumference based on reduced tolerances and removing overlapping eyes 2mm ● Also added holed to lids ● Create version 5_ 4 with smaller socket- 1mm ● Crated version 5_6 ● Meeting with Ainslie; ○ Likes version 5 ○ Need to increase space between lid and cup to 1.5 ○ Ask Fabio two create print 2x big eye set with 2 different eyeballs

	from the set and medium test. ○ Grey resin is good - but white still needed for eyeball ○ Create smaller eye working of 75% scale eyeball 15mm ■ Keep socket 1mm ■ Lids 1mm ■ Cup 2mm Created version 5_5 - smaller socket, eyelid control holes Created version 5_6 - smaller socket bigger spacing between lid and outer cup Created version 7 - 75% version based on eyeball of 15mm - also known as medium
Time	2hr
images	  
video	00000340-VIDEO-2020-06-11-16-55-03
Date	12/6/2020
Activity	Created medium eyeballs Added eyelid control hotels to version 5_6 & 7 Checked with Ainslie Sent on to Fabio for possible print
Time	1-2hr
Images	  
Date	16/6/2020
Activity	Fabio confirmed he will print today or tomorrow all part’s requested Ainslie sent photo of delivered materials form GoPrint3D; ● Incorrect elastic print (wrong file-not file of ours) ● white resin parts sticky and uncured

	Action taken: ● Emailed GoPrint3D ● GoPrint3D apologies and will resend entire job - due to arrive Tuesday Ainslie asks if possible to print eyeballs in halves for FDM test Laura raised these issues; 1) tolerance: we'd have to account for the tolerance change between the two which shouldn't be a problem but I'd need to know what to work against. 2) printing a flat object onto a bed can lead to curling or warping due to heat and extrusion - so you might not end up with two perfect semi circles especially if you consider the hole for the pupil etc 3) post print would you want to smooth out the lines as this may take a while and lead to imperfection from either over sanding or uneven sanding Laura will create files and tests on her own printer to send with resin tests when they are picked up.
Time	1hrs
	 
Date	17/6/2020
Activity	Tests; ● Halves of full eye one form round one form slit pupils ● Halves of full medium size one form round one form slit pupils ● Create versions with reduced circumference by 0.2 to check for tolerance insurance ● 0.2 eye halved one form round one from slit pupil ● 0.2 eye medium size halved one form round one from slit pupil ● Whole eye 2xfull 2xmedium one form round one from slit pupil ● Whole eye 2xfull 2xmedium one form round one from slit pupil on stalk to help with plate addition in printer. Put to print: ● version one ○ Full ○ Halves ○ Stalk

	○ Full_medium ○ Halves_medium ○ Stalk_medium ○ Started printing at 12PM ○ Set shell wall line to 4 - to reduce need for infill ○ Cura suggest print time of 2hr03min ○ Currently printing for 3hr22min including warming up. Results unsuccessful
Time	Modeling: 2hrs Printing: Started at: 12PM -15:43PM - 3hr43min w/heating+setup
Images	 
Date	18/6/2020
Activity	Ainslie request FDM files for someone else to print near him
Time	20mins
Date	19/6/202
Activity	Pick up prints from Fabio. Suggested tweaks. Perhaps removing bevel to clip holes- but not worth pursuing Posted to Ainslie
Time	1hr
Date	21/6/2020
Activity	Ainslie sent images of resent prints from Go Print (arrived 20th June 2020) Sent an additional rubbery cup Eyeballs to small again rubber material - increase volume to make flush in design (10mm to 10.4mm)
Time	20mins
Date	22/6/2020

Activity	Posted eyes arrived, large eyeballs a little large suggest increasing the volume Medium set little tight but sanding should help Suggest increasing internal socket of large eye by 0.3mm so there is only 0.2 tolerance to create tighter fit Completed and sent to Fabio Broken lid- asked Fabio to print replacement Discussion on which eye to get printed through DoPrint3D Ainslie to decide tomorrow
Time	1hr
Date	23/6/2020
Activity	Fabio to print increased large inner cup with 0.3mm inside reducing tolerance to 02.2 Contact GoPirnt3D to print. ● Remove most slitted eye (4) and add 2x (1) & (2) to both medium and large set ● Get two of every eyeball printed ● Large and medium socket sets (lids & cups) ● In white resin Also discuss an extra x 2 of cups, sockets, and lids as an addition
Time	2hrs
Date	24/6/2020
Activity	Quote form GoPrint3D, 130+pp. Waiting to hear about additions. Double check this is just white resin and does not flex.
Time	30mins
Date	25/6/2020
Activity	Turns out inner sock was quoted as flex so is actually $115 +pp Additions of 2x cups, socket, and lids - £50 take 4 beds to fill Had also sent them slight wrong small eyeballs (10mm rather than discussed 10.4mm to account for flex sockets) Also, Ainslie re-emphasized that they try to put into the bed flat to reduce support and warping around eye holes. Ainslie to pay. Hopefully arrive next week

Time	1hr
Date	29/6/2020
Activity	Laura collects print from Fabio - minor confusion only one socket printed - to collect later in the week
Time	20mins
Date	3/7/2020
Activity	Ainslie received prints from GoPrint.
Time	9 days to send form printers
Date	6/7/2020
Activity	Final second socket collected form Fabio and posted on to Ainslie.
Time	30mins
Date	8/7/2020
Activity	Ainslie received final grey prints; minor issue with white cups 20mm being a little loose but new grey 20mm perfect. Laura suggested that this is due to minor imperfection in printing where the same object printed at the same time using the same file can have tiny anomalies and differences. However, as Ainslie is adding varnish and materials to their eyes this may make up for minor imperfections.
Time	Two days postal delivery
Date	12/7/202
Activity	Laura asks Ainslie for update on developments: Ainslie has been working on painting eyes, before varnishing and experimenting with wool see image below.
Time	n/a
Date	27/8/2020
Activity	Ainslie completed eye mechanism and shares via video explaining process and functionality.
Date	3/9/2020
Activity	Update on puppet development, slow progress due to illness
Date	11/9/2020
Activity	Update on eye mech

Date	12/10/2020
Activity	Arranged conclusion interview for Friday 16th October
Date	16/10/2020
Activity	Conclusion interview transcript found appendix B.3. Analysis of study and findings in chapter 6.
Time	1hr

Bureau Services List

Name (link)	Material	colour/ finish/ texture	Min detail (d)/ Clearance (c)/ Tolerance (t)/ Accuracy (a)	Wall thick Ness (min)	Water proof	flex	Cost (est)	Time (approx)
I.materialise Belgium	Grey resin (SLA)	grey/ Spray paint whit+	0.5d/0.3c/	1-3mm	?	no		8 day
	Polyamide (SLS) laser-powder	white+/ satin(+2days) polished(+2days) velvet(+5day)/ raw=granular	0.3d/0.5c/0.6t	0.8-1mm	w/finish-only in white +1day	no		6 days+
	Polyamide (MJF) Slight flex	gray/ Dyed-blk(+1day) Polished(+1day)/ granular	0.25d/0.5c/	1mm	?	slight		5day+
	Polypropylene laser-powder	white/granular	0.3d/0.6c/0.6t	0.8-1	?	no		10 day

	Rubber-like (MJF) Powder-fused jet	grey/granular	0.25d/0.5c	0.8	?	yes		4 day
GoPrint3D RIPON/ North yorkshire	Formlab - Greyscale Resin	Blk,White, Grey/ matt-opaque/	0.4d/0.5c/0.5t Minimum hole 0.5 Connection 0.2 or 0.1snug	0.6		no		5 days
	Fromlab - Grey Pro	grey				no		
	Fromlab - Rigid	white				no		
	Fromlab - Flex	Blk				yes		
	Formlab - Elastic	Clear				very		
	Formlabs - Rebound (stronger)	Blk				yes		
Shapeways The Netherlands	PA11 (SLS) Laser-powder stong	white/rough-matt	0.4d/1.0c/1.0t? +0.3a	0.4 0.5 support wall	yes?	no	Min $10	4-6 days
	TPU (SLS)	white	1.0c?/1.0t?/+0.3-0.7a	0.7		yes	Min $15	Within 13 days

	Versatile Plastic (SLS)	white+/ - Processed -Premium/ rough-matt	0.2d/0.5c/+0.15a	0.7	yes?	no	White Raw $5 - Proc $7 - Prem $9.50	4-6 days
	Accura Xtreme (SLA)	grey/support removal-sanding/smooth	0.3d/0.3c/+0.2a	0.4 wall 0.5 support wall	yes	no	$30	6-10 days
	Accura Xtreme White 200 (SLA)	white/support removal-sanding/smooth	0.3d/0.3c/+0.2a	0.4 wall 0.5 support wall	yes	no	$30	6-10 days

Appendices B.2 – Original email sent to Collaborators.

Dear Will and Ainslie,

I hope this email finds you both well. Thank you for allowing me to use clips of your work in my presentation this summer at the Essay Film Forum in London, it was really useful in getting my point across about how making-of videos are a form of research methodology and fulfill multiple criteria for both research referencing and dissemination - it wasn't as dry as it sounds, I promise.

I wanted to ask if you'd be at all interested in talking to me some more about your work. As you may or may not be aware, I am currently doing a PhD in Bristol about the use of 3D printing and digital fabrication tools in the stop-motion animation industry. I am looking for interview participants and possibly collaborators for my final project. I have recently been looking at developing a film using 3D printing that narratively uses making-of storytelling in combination with glitch art to create a film that discusses and showcases the work I have been looking at and developing during my PhD. I am aware that both of you are extremely busy but wanted to ask if you'd be at all interested in collaborating or mentoring me on this project.

The aim of the film is to create a narrative that is sympathetic to visual concepts of the film (glitch art, errors) by combining 3D printed objects and stop-motion animation, whilst narratively not being entirely devoid of emotion or character development and hopefully humor. There have been multiple films that have used 3D printing as a gimmick and films that have been created to showcase the splendor of what 3D printing can do, however what I would like to do is to use 3D printing as a tool to reveal something character-based about filmmaking, post-digital tooling, and issues of engagement with future tech without being preachy or maudlin.

Your work has been a tremendous influence on me throughout my education and your recent projects, I feel, parallel a lot of the themes I'm trying to create in this film. I would only expect notes and potential scripting suggestion and your involvement would be largely down to yourself and your schedules. However, I'd love to work with you both. I intend to apply for some academic funding as well as film funding for this piece to allow me time to work on the film and pay for materials; if any further funding became available, I would of course come back to you and ask for your fee. However, at the moment I'm proceeding with this project with an auteur/no budget mindset.

Please feel free to say no to anything I have suggested, but I feel it would have been remiss to not come to you both directly as your work has influenced me so highly and I feel it would be a great fit.

All the Best,

Laura-Beth Cowley

Appendices B.3 – Conclusion Interview Transcript.

INTERVIEW DATE/TIME: Monday, October 10, 2020, 13:24:00 PM - 14:19:00PM GMT
Laura-Beth Cowley (PhD Researcher) , Ainslie Henderson (Auteur Filmmaker/Director)

- -

Laura-Beth Cowley 01:06
Can you start by telling me briefly about yourself and your career as a filmmaker/ animator?

Ainslie Henderson 01:15
My name is Ainslie Henderson. I am an animation filmmaker. I work almost entirely in stop motion animation. I am definitely an auteur. I like every part of the process from writing to making my own puppets and animate everything myself. I am basically a little bit controlling and obsessive, and so I cannot bear to give anything up. Which is why I tend to make personal films and have not a lot of money. Most of my career has been making short films. When I graduated from Edinburgh College of Art, in 2012. I made a film called *I am Tom Moody*, that did quite well around festivals, and so on. So that gave me an in. Then I made a load of music videos, one of which was called *Moving On* for a band called James. That was quite well received. I made a film in 2014, called *Monkey Love Experiments*, which was the only film that I didn't make the puppet for entirely. A puppet maker helped me make that one. Then a film called Stems, which is a very short two-and-a-half-minute film about the process of puppet making.

Currently I am working on a film called *Shackle*, which will be filmed outdoors in the woods. The things I most dislike about stop motion animation is that you tend to have to make it in a dark room. And I don't like dark rooms, I like being outside in the trees and in the countryside. So, for a long time, I've been yearning to move animation outside. So, this is an opportunity for me to do that. The other thing I don't like about animation is that you have absorb it through a screen. I'm also not a fan of screens. So that will probably be the next project, finding a way of making animation that you can enjoy not through a screen. I've had one experience with that, which was made with my creative partner Will Anderson who I work with a lot. He and I made the animation for a stage show called Flit by Martin Green, which toured in 2016. It was like halfway between a gig and a piece of theatre, which we made animation for that was projected onto the stage, I'd like to explore more in the future.

Laura-Beth Cowley 04:41
Okay. So, can you describe your current film and the circumstances of its production?

Ainslie Henderson 04:55
It's being funded through a scheme that the BFI put together to help filmmakers, who are not at the very beginning of their career but are looking to push their work. I've noticed that for at least the last 10 years, the big awards in Britain such as the BAFTA's and the BFI awards, always go to students, which is great. In that it gives students a platform and students have the time, access to the equipment and the attention to innovate things. However, it does say something a

little depressing about what happens to animators beyond being a student and the state of short film in Britain, there's not a lot of advancement. So, I think the scheme will help address that, not to help give filmmakers a chance to win more awards but an investment in short film to assist filmmakers in making something that's of a higher quality.

Laura-Beth Cowley 06:50
could you go through the process of how you got the funding?

Ainslie Henderson 07:02
Will Anderson is producing it, and I wrote and directed it. The application process was quite gruelling, which it should be. We had to write a script, audition through video, talking about the film, what it was about and what we wanted to do. Then we were whittled down through rounds. we had to go down to the BFI and be interviewed about the film and we were lucky enough to get it and I'm really pleased we did. It's certainly given me something to do during the COVID lockdown.

Laura-Beth Cowley 08:11
Can you say in your own words, how our collaboration began? And why did you initially think of using 3D printing for this project?

Ainslie Henderson 08:24
It's a good question. Something that frustrates me about my own process and something that I feel determined to change on every project. But for some reason I never manage it, is there is no continuity to my puppet making process. I look at other animators, and they seem to have a sense of style, or a kind of certain technique that they go back to again and again, and it evolves. But essentially there is something at the core of it, that they recycle. And I for some reason, I never seem to manage this, it feels to me like every time I come to making puppets, I'm starting from the beginning again, to extremes that are absurd. I find myself on YouTube, looking at videos of how to make a wire armature from step one. I have been doing this for, nearly 15 years. I should know what I do, how I start, but for some reason I don't. I find myself back at the beginning every time and in 3D printing, part of the appeal was I thought I could design something that could be scaled up and down and reused and restyled and repurposed every time. So, I’m not starting from scratch. I was aiming to do this with eyes and with mouth. Partly because they are the most difficult things to build and the eyes in particular, I've always thought that if you've got expressive eyes, and expressive hands, then you can do anything with puppets. I think they're the most important elements. So, with 3D printing, I wanted to make eyes that I could faithfully reproduce again, and again, which I could paint differently, and coat and skin, the eyelids differently. But the mechanics, I could just reproduce without having to start from complete scratch every time.

I also wanted to make some eyes that could move with precision, I thought, if I could make a really well-crafted eye that sat in a socket. With real accuracy, then I would be able to move the eye in a very, very precise way. In past films such as *I am Tom Moody*, and a couple of the others, I’ve found that it's that tiny little way that humans move their eyes with tiny little increments, they're always shifting around a little bit. And I think that's a key to real aliveness. I think eyes that move with great accuracy, make puppets look like they're thinking, and that really excites me. So, 3D printing felt like a way of being able to do those things make eyes that move with accuracy and I can reproduce again and again. So, I started messing around with blender. I'm typically kind of a Luddite, I don't really work with a lot of technology. I like working with my hands, I like physical things. But I loved getting to know blender, I really enjoyed the challenge of it and really got into it. I met someone in Newcastle at a place called Eagle labs, which was basically one of these offices that banks - this happened a lot in the last 10 years - banks took over physical spaces that were closed on high streets and set up little tech labs where they let people use the tech for cheap and I think the hope was that they would innovate something and then the bank could invest in it and they would work together on it.

So, it was a little lab set up by Barclays in Newcastle where I was making eyeballs, it was just like two arms that came around and clung to the eye. They were made using FDM printers and they were terrible, but it was exciting for me to build and to design this one eyeball and then be able to get 20 eyes printed, and just churn them out. In the past I have done lots of things, like getting marbles and trying to drill out a marble and plastic balls. I have loads of plastic balls from different industrial websites. The FDM printing was also frustrating because they would come out slightly wobbly, slightly wonky and covered in lines so they would kind of crunch and click and they wouldn't move together with any smoothness and moving beyond that, in the world of printing was just a whole world of things that I didn't have time to start understanding and it was about then that you got in touch.

You emailed me and said that you were doing a PhD in which you wanted to make a film that utilised 3D printing. Then you and I spoke briefly about making a film together that had 3D printing at the heart of it, which I was really excited about. But then right at the same time, I was given the funding from the BFI to make *Shackle*, so I knew I had to prioritise that. However, I was experimenting with 3D printing for the eyes. So, we had a conversation about that, and it turned out that you would be able to help. Yeah, and you had an insight into 3D printing that I didn't. It just seemed like a really helpful and easy collaboration.

Laura-Beth Cowley 17:06
How would you describe your ideas and knowledge around developing objects for print and animation before the case studies?

Ainslie Henderson 17:34
I knew very little I had a bit of experience printing eyeballs in FDM. I was also interested in scanning things; I'd scanned an Apple at that point by taking the hundreds of pictures on my phone all around it and I was going to print that out. I had a basic understanding of blender and then of Cura. I had no understanding of the different materials that you could print in. I had no understanding of the stage between really designing it in blender and then pressing print. You brought a lot of things about tolerances and spacing and how best to do things and materials, what different materials there are and what properties they have. I mean, I still have very little

understanding of it all really, I have a slightly expanded understanding of it, but because we work together, you took care of all of that.

Laura-Beth Cowley 19:58
How have you found the process of working with the researcher on the case study?

Ainslie Henderson 20:05
I found it really helpful. Like I said to you at the start, I tend to burrow down into a little hole, when I'm making films, just trying to do everything, myself, and it can get a little overwhelming. So, to have another mind that has that focus was on the technical accuracy of how to put things together has been really helpful. It's a lot of fun collaborating on the design of it and trying to figure it out. I think as well, just because I knew I was going to be building the puppets that came from the 3D printed eyes and lids and sockets. I was always pushing for things to be aesthetically as I wanted them to look. And often you would be pushing back with the technical kind of restrictions of knowing what the tolerances of the material and you were right.

The one thing that has gone wrong is I have had a few things break, where I've wanted them thinner and thinner and lighter, and smaller and tighter. And because I knew that would look better, by being less chunky and with smaller spaces by paring parts down. So, I would always be pushing to have them look better, and you would always be that voice of the practical. This won’t work because of that, or this will break. If you keep shaving bits off these little clips, they're going to break when you use them. That was helpful. I think I would have spent a lot more time and money printing things out that didn't work properly. If I had been doing it without anyone else.

Laura-Beth Cowley 22:29
Okay. In what way has the case study benefited you and your project?

Ainslie Henderson 22:44
I think I have a set of eyes that are going to work better than any eyes I have used in the past. Particularly the eyelids the way that they can close and open and emote. I have not animated with them yet but from the way they feel, I think they'll be more effective than anything I've had in the past.

Laura-Beth Cowley 23:15
I was lucky enough to have a look at the script. So, I have an idea of how they feature in the film. But could you discuss how linked the eye mechanism is to both the functionality of the project and the narrative of the film overall?

Ainslie Henderson 23:33
It is hugely important, in that this is a film that doesn't have any dialogue in it. There isn’t a lot of action. So, a lot of the emotion and a lot of the dynamic between the characters comes from what they feel about each other. When they think of each other and how they interact. In that way, it comes down to what they can emote through their eyes. So, I feel like it is really

important. There are a lot of close ups, and a lot of them watching each other and reacting to each other, just through their facial expressions. The design of the face is essential to letting me animate that well.

Laura-Beth Cowley 24:25
And correct me if I'm wrong but isn't there a narrative point in the film where the ability to change the eyes is part of the story?

Ainslie Henderson 24:41
Exactly. Yeah, there is a kind of motif in the film when each character enters a more selfish reptilian mode of thinking were there eyes actually change. So, we had to make sure that the eyeballs can come out of the sockets quite easily and be replaced with other eyes. That is a movement through the story that's made possible by the mechanisms that we had to invent.

Laura-Beth Cowley 25:29
And practically you're working in a real-world environment can you tell me if/how the eye mechanism aids with this?

Ainslie Henderson 25:45
Because I'm going to be working outside, the pressures of working quickly, will be huge. So, I knew I needed the eyes to be very easy to manipulate. I've had eyes before where I've had to get pins and put them in and move things. Like when you work with plasticine where you have to re-sculpt each frame, it can be really time consuming. You can lose an hour suddenly just finessing things. So, I knew I had to make the eyes easy to work with, quickly and go back to how they were. Without too much messing about, I can't be mucking about in the forest.

Laura-Beth Cowley 26:39
Reflectively can you remember if there were any drawbacks or problems during the process?

Ainslie Henderson 26:45
Yeah, I have made the clips a little too thin. In that when I sculpted and fitted the whole thing together, I have accidentally broken one off. It's very, very, very thin, which I know you pointed out several times when we were making it and I said it'll be fine. It'll be fine and it isn't fine it's too thin. You were right. I'd also say they're difficult to put together. The way we have designed it, with the socket with a lower lid, hugging it, and then another lid that goes over the top of it, then the whole thing was inside a cup. When there covered in fur, it's a bit of a gabble, getting them all to fit together and then push inside the cup, it can be difficult to make them slot together. So, if we were going to do it again, I would want to look at that. I don't know what the solution would be, maybe a case that closes around it somehow.

Laura-Beth Cowley 28:18
It's that difficult balance between keeping them encloser so that anything you attached outside of it didn't then affect the mechanical function, wasn't it? So that was why it needed to be

enclosed, so that when you are gluing and felting parts to the surrounding head, it wasn't not going into the eye system itself. It is all about compromise.

Ainslie Henderson 28:37
Yeah, it is. But when putting them together, that has proved pretty difficult. Constructing them.

Laura-Beth Cowley 28:53
So, from the point of having the final printed parts what has the post pressing on the system involved?

Ainslie Henderson 29:12
Well, there's obvious things like there are the little spurs or little drips that you need to file off. I use a Dremel to make sure they are all smooth. I have been trying to make these puppets out of natural materials, using loads of wool and feathers. I have been coating the lids in wool that I've kind of rolled with glue, and then slightly burned and then pushed and then cut into strips so that the eyelids have a kind of ribbed warm look. I have been using feathers as eyelashes, which I don't know is it will work but I've been playing with that. Basically, a lot of the post has been trying to cover over the plastic in any way that I can because I want these to look animalistic, so any little crevices of plastic shining through kind of gives it away.

Filing things down and covering them in fur, even if it is just a little bit of felt to stop, light catching it and reflecting it, is what I've been doing. That is for the eyelids and the sockets and then the actual eyeballs. I am delighted with the eyeballs, as they are actually hollow, I was able to paint the inside of them black. Then I paint the irises with oil paint. And then I fill it up with see through doming resin. So that the top of the iris has a dome on it like an actual eye. I love that you can look inside into a black hollow, it makes it feel very, very real. It is like an actual eye, which is pretty exciting.

Laura-Beth Cowley 32:12
How would you describe your thought process and knowledge now regarding 3D printing?

Ainslie Henderson 32:19
I mean, it is slightly more refined, I have a practical understanding of how thin you can print things before they become too brittle. That is one thing, I have been surprised at how brittle this material is, what was it again?

Laura-Beth Cowley 32:40
we only ended up using grey resin, there is a harder form. But we decided not to go with that.

Ainslie Henderson 32:47
Right. Yeah, the grey resin surprisingly brittle. I feel like I have only just scratched the surface of it. I feel kind of excited about 3D printing. I would love to do more with it. I would love to do more of the high end beautifully finished objects. But I would still like to do more with FDM. I would love to do more with just an FDM printer at home. I feel like there is a lot of exciting work

to be done there as well. It is like if you can build that kind of imperfection into the style of your work. It could be a lot of fun.

Laura-Beth Cowley 34:08
So, do you feel the technology has further applications for your work in future?

Ainslie Henderson 34:16
I will definitely be making more of these eyes. I think that there absolutely is. I would like to make the film that you and I talked about that conceptually has 3D printing at the heart of it. I find that exciting. What is exciting is seeing something from that 3D digital realm in our world. There is something really uncanny and odd about that. Lately, I feel very excited about the idea of being able to design something that looks fluid and is printed out maybe in replacements. To be able to design fluid movements digitally, and then have them printed out and then have that play out in the real world. It feels like there is a lot of things that I've not seen yet done with 3D printing which is still to come.

Laura-Beth Cowley 35:49
If this question doesn't make sense, I'll elaborate but how do you feel the technology has impacted your level of control and authorship in your work?

Ainslie Henderson 36:01
How is the technology impacted my control and authorship? Yeah, tell me more about that question.

Laura-Beth Cowley 36:10
I am interested in the conversation around authorship. The idea that, there's a classic idea of what an author is in a film, such as Disney for example, and how all his work is similar or readable as coming from one authorial creative, even though we know he worked with many people to make that body of work come together. Compared to yourself as an auteur filmmaker, who is everything in a film, you are the director, the story you are everything. In a large production, where you have many, many, many different departments, there is a concept that there is authorship at different levels, or potentially ownership at different levels.

So, when you look at a film say by LAIKA, where they 3D print millions of faces, I'm interested in this idea that as an animator on that production, you may feel like your authorship over the performance of a character is taken away slightly by the fact that all of that facial animation, which as we have discussed is such a big part a performance, is taken away because you as the animator don't necessarily have any control over that element. And as they add more and more replacements, that authorship and creative decision-making keeps getting tapped away at more and more, because those conversation between the animator, the CG animator, the director, is breaking down or reducing just because of time.

Which is not so much of a concern when you think of auteur films, because you are involved in everything. But as this collaboration worked, you were involved in as much as you could be, but at some point, there is a kind of skill break off point. Which is the idea I am interested in, I think 3D printing is amazing, but to expect craft people to necessarily have the digital skills to meet what they want to do, I think is a tricky balance. I think ideally, you would be able to do all of it, how to use blender, or CAD or whatever you need to get what you need to do. But I feel that this expectation is possibly unrealistic. So, what I mean is do you feel this technology has impacted your control over this project and your authorship as a filmmaker on this project?

Ainslie Henderson 39:08
I understand. I think that it affects me but not in a massive way in that. I think there's a couple of things, one is that because I had a big part in designing what we wanted it to look like to begin with I felt I had still maintained a certain amount of control there and then there's a compromise, which there always is, even when you're working entirely with plasticine, or wood, the materials all do some things well and don't do other things. You are always slightly compromised by that.

I was maybe slightly more compromised because I was designing eyes on blender. And my capacity to use that tool is basic. Maybe the eyes were more generic, it was just kind of generic shapes. However, that was less of an issue because once you had helped design and then finesse those more generic looking eyes. I knew that after that, I would be able to take them, and then sculpt and build on top of those plastic shapes. So, I wanted the eyes to become a template, or foundation that I could then build on and make different styles from there. If you look at the pictures I have sent already, I've made two characters so far. And they are very different looking eyes, and they are both made from the same, the same basic templates.

Laura-Beth Cowley 41:28
It sounds like that's what you were looking for, from 3D printing is a is a core base that you could return to in the future.

Ainslie Henderson 41:35
Exactly, that could be adapted to look very different.

Laura-Beth Cowley 41:41
I think that is one of the more unusual things about stop motion animation as a way of making is that almost everything is bespoke. As in it is unlikely that you will make the same puppet more than once unless you are making replicas for that same film. There is an idea of a standard armature piece, or way of making an eye, but unless you're going to be working on a series, it's only the standard for that series or production, or maybe that animation studio, it's very unusual to have an industry that's so craft and mechanical and engineering lead but yet has no standard consistently repeatable way of making.

Ainslie Henderson 42:29
There are some standard things, such as armature parts and so on,

Laura-Beth Cowley 42:33

Even then they are very adaptable, like even a sandwich plate joint, is dependent on the function of the puppet. How you are building it, how long the limbs are, how wide the hips, and scale all change the standard form. You can of course buy standardised kits, but it's all customizable.

Ainslie Henderson 42:56
Yeah. I've seen some things; you can buy eyes. I think that maybe that is what the new technology has let me do. I've bought eyes online before, then at a film festival I'll watch a film with a character that has the same eyes as my mine, and I don't like that. It is soul destroying. It is through the development of 3D printing, that have allowed me to do this and to make my own my own sockets and eyes and know that no one else will have them.

Laura-Beth Cowley 43:45
to create something, ultimately completely bespoke.

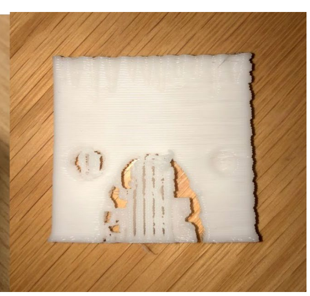
Ainslie Henderson 43:48
Exactly.

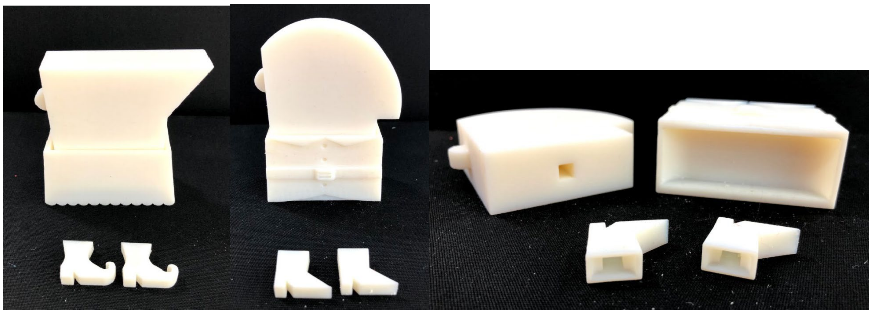
Laura-Beth Cowley 43:51
Final question. Do you have any further thoughts on how this technology could aid filmmakers' artists like yourself in future?

Ainslie Henderson 44:18
God that's a difficult question. I have a friend who is a digital artist and he's getting really into blender. Something I've notice is that there is a massive community, online of digital artists who are talking about this piece of software, they compare methods of working and how it can be used. Which I think is such a valuable, and exciting thing. I would like to think that 3D printing could become more like that.

As independent artists, we are very separate, in our own little worlds, particularly animators, we work in our own little bubbles and with 3D printing as a technology, I think there is an opportunity for us to collaborate with each other and share these ideas and understand what we are all doing. I realise that's kind of contradicts what I was just saying about the potential it gives you to make unique bespoke designs. I suppose it is the other side of that, it lets you innovate things yourself. I think there is a real opportunity for us to pool all those innovations and share them and understand what we are all doing. I would like to see that happen more; I would like to be part of that.

Appendices C.1 – Project Log: Novel Film - Crafty Witch.

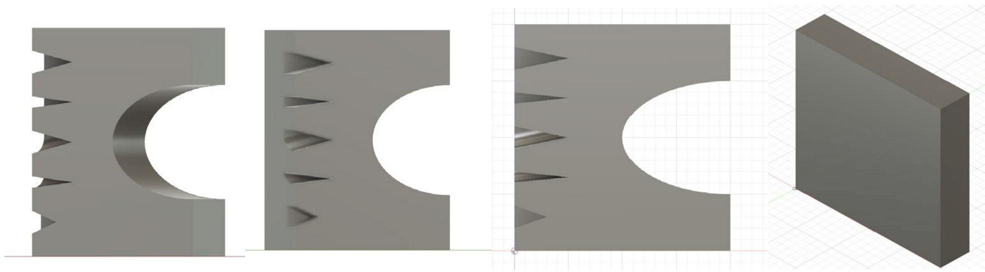
Project	Film - Crafty Witch
Participant	Laura-Beth Cowley, Sam Shaw, Hannah Stevens
Date	18/4/2019
Activity	Initial test fusion models - Witch
Time	2-4 hrs
Date	20/3/2019-18/4/2019
Activity	Initial test fusion models - Hunter
Time	2-4 hrs
Date	25/4/2019
Activity	First 2D animatic test created with Hannah Stevens's storyboards
Time	2-3hrs
Date	2/6/2019
Activity	Initial test printing to trial both new printer nano easythread and line quality and test piece
Time	3-6 hrs
images	 
Date	3/7/2019
Activity	Redesign of both hunter and witch characters
Time	4hrs
Date	11/7/2019
Activity	Some powder printer tests, set up, print and cleaning. Some issues getting slicer to accept the files- due to typology. Reasonable results/heavy- shows potential

	for better finish if required- not what I'm look for with this project
Time	3-6 hrs set-up, print, cleaning
images	
Date	29/7/2019
Activity	re-design
Time	2-3hrs
Date	15/3/2020
Activity	Met with Sam Shaw to discuss collaboration on animation.
Time	1hr
Date	4/3/2020
Activity	Re-design thinner
Time	2-3hrs
Date	8/3/2020
Activity	First draft of animatic completed by Sam
Time	20min
vidoe	Material folders> Chapter_8_CraftyWitch>Animatic_CraftyWitch.mp4
Date	9/3/2020
Activity	Test prints using Lulzbot. Discussed using a larger nozzle size to create increased line size. Asked in the Fabrication department about this. Booked in next week to test machine **[covid lock down canceled this appointment and stoppered progress on this project as a new way of working was put in place]**
Time	2-3hrs
Date	23/5/2020

Activity	Applied for animation review opportunity with Linoleum festival in Ukraine: LINOLEUM Festival launches a new experimental project - Animation Reviews! The aim of it is to provide recommendations and advice from animation professionals to authors whose projects are at the stage of development or production. How it's going to happen: 1. We announce application submission for projects created in a particular animation technique. The first Animation Review will accept stop motion projects. 2. You fill in the application form and submit it prior to the deadline. 3. We invite international mentors (director/producer and animator) for the pre-selection of projects (the number of selected projects will depend on the number of applications received). 4. We announce the participants of the Animation Review and send over detailed information by e-mail. 5. Selected participants will join a Zoom meeting on the specified dates, where they will present their project directly to mentors and receive professional feedback! Key dates for the first Animation Review (only for stop motion projects): - Deadline for submission is May 31. - Participants announcement will happen on June 15. - Meetings with mentors will take place online via Zoom on June 20-21 (detailed information and the exact time each selected participant will receive via e-mail). To submit your project, please fill out this application: https://cutt.ly/5ynQFyM
Time	30mins
Date	20/06/2020
Activity	Received feedback on film ideas and visual concept form industry with Tim Allen and Irida Zhonga. As part of the Linoleum animation festival in Ukraine. Suggested working on multiplane set up to reduce the need for rigging and post-production editing
Time	01:20
Date	7/10/2020
Activity	Applied for funding for ender 3 printer to continue research in lockdown
Date	21/10/2020
Activity	Was granted funding for Ender 3 and additional time to continue research

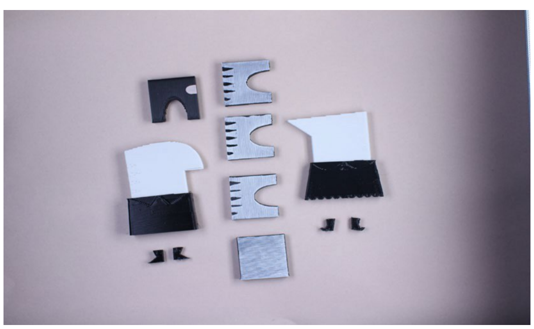
Date	25/11/2020
Activity	Picked up printer
Date	27/11/2020
Activity	Unpacked and set up Printer
Time	3hrs
Date	2/12/2020
Activity	Turn on and test print for set up/read up on hero 5 update
Time	3hrs
Date	3/12/2020
Activity	Sonny meeting 12pm to talk through update of volcano purchased bolt update began setting up prints Collected all the files for machine updates Took apart a hot end casing to see if I could see it's electronics. I couldn't Leveled printer. Begin printing hero 5- testing 0.2 layer height 50%infill.
Date	4/12/2020
Activity	Print part of hero 5 multiple fails. 2 parts completed Turbine fan, led bar & gantry clip. Multiple FAILS with adhesion, re-leveling and reduced layer height back to 0.12. Attend blender training at CSM
Time	All day
Date	6/12/2020
Activity	Print 2 parts cone collar & air dam. Print parts 1 x duct standard left and 1 x right halfway through fan 10hr print-FAILED spilled out.
Time	15hrs- printing, 2hrs set up
Date	7/12/2020
Activity	Begin print - print needs re-leveling, lightweight standard left duct standard

	Print gantry adapter - increase infill to 90% try again 0.2 layer height with initial layer of 0.12.
Date	14/12/2020
Activity	Met with Sonny at Bower campus to make adaptation to the hot end for larger nozzle printing. Decided to rewire part cooling fan as well as hot end, was able to keep original hot end fan. Re-leveled and adjusted x axis sensor. Partial test, slightly tilted bottom layer perhaps due to cooling, suggested adding split double fan.
Time	7hrs
Date	14/1/2021
Activity	Updating printer to double dual fan And printing a filament holder to help reduce tension on filament. A couple of failed prints at 0.4 with cura standard 0.8 nozzle settings, Increase temperature to 205, plate temp to 60, print speed reduced to 40 and for the double duel I added a brim support to double down as it was having additional issues on the first layers- may re print with support as the connectors are a bit messy. Filament holders will not fit together- improved quality may be needed. Or may try a different design.
Time	4hrs
Date	15/1/2021
Activity	Re-print filament guide add on @ 0.8 nozzle 0.2-layer height, temp 205, plate temp 60, speed 40 at 99% scale- it did not fit set up Create a test piece for next week layer tests - it doesn't seem 0.6 nozzle test will be needed if anything a 1.2 nozzle purchase may be worthwhile, but I will try 0.8 with various layer heights and then move on to 1.0mm I predict the test due to print times and analysis to take a week. I will first need to create a useful test based on possible needs of the characters. I think I will remove depth and the quality at the higher levels may prove tricky especially if support is needed for open mouth. Teeth could be added separately Good print - A thin 3D cube with some cut depth and small cut out to test layer and nozzle heights. [image shows test_peice_1 - simple square / test_peice2 square with cutaways] - reduce scale of piece 1 by 50% in slicer as to big for

	testing. Created nozzle layer data capture log and nozzle layer test log for analysis of test as they go through - today tests 001-006. Look at buying 1.2 nozzles. Also look at reducing support for inside of cut out to reduce post print processing.
Images	
Time	6hrs
Date	18/1/2021
Activity	Printed tests 007-009 - interesting results from 0.8 layer height with 0.8 nozzle- can't really take the layer height further than this because it would then be extruding beyond its nozzle diameter. So, I have logged and moved on to test piece 2 which includes constructed detail nicks to the left side and a fully cut out shape to the right, the cut out in particular is important to figure out how to originate the prints, as extreme overhangs will be a key part of the puppet.
Time	4hrs
Date	19/1/2021
Activity	Printed test 010-012 - issues with overhang and support . Ordered paint and brushes for painting tests. Paint choice currently Winsor & Newton Galeria Acrylic in Pale Umber. I want to stick to a base paint that is easily findable and replaceable to make sure there is as little colour variation in the post processing.
Time	4hrs
Date	22/1/2021
Activity	In order to fix the support issue, I began looking for alternative support structures, I had seen ways of adding your own support so downloaded that plug in for cura but whilst looking for that I also watched a video showing and explaining the differences and benefits of normal and tree support structures. So will test these before moving up in layer height or nozzle height. Once this issue is addressed the rest of testing should be relatively straight forward. **YouTube links;** Manual supports: https://www.youtube.com/watch?v=N6w2KX-BUUk Tree support/settings: https://www.youtube.com/watch?v=7BURpQNXrDA&list=PLRFPlUhDTTlmascsMmXw8qK6265ZNfV41&index=39

Date	1/2/2021
Activity	Recalibrated printer did further test for 014-016. Solved support issues- still slight warping and detail is not crispy- may try creating alternative design tests, to redevelop detail parameters. .
Date	2/2/21
Activity	Did further 0.8 tests 017/018- Fina 0.8 tests moving on to 1.0 nozzle tomorrow.
Date	3/2/21
Activity	Was going to change the nozzle but needed to wait on tools to change the hot end.
Date	5/2/21
Activity	Tools arrived yesterday but have decided to run two more tests with new test samples to try and get a better quality on the detail elements.
Date	6/2/21
Activity	Ran two further tests and changed hot end out for 1.0 nozzle test, print test to check if installed properly.
Date	8/2/21
Activity	Initial print test of 1.0 nozzle with 0.75 layer height, was good, but did not show much increase in layer height or detail. Further test to be done
Date	9/2/21
Activity	After further research into layer height more parameters have been changed. Video on nozzle size settings; https://www.youtube.com/watch?v=tM5obc-VLpQ https://www.youtube.com/watch?v=jyhLQUQTc9E Summary: Suggestions that when increasing a nozzle size, you may need to increase temperature of extrusion, rescue speed and add extra top layers. The benefits and drawback of larger nozzle can be seen as follows; +Faster +Stronger -less detailed -uses up more materials >creates rounded edges >creates more defined layer lines The last two of these I have separated out as they are neither negative or

	positive but more a visual analysis of the use of these nozzles, that may prove beneficial. Of course, for this project this is what I am choosing to use to create a novel visual Identity.
Date	10/2/21
Activity	Print tests 1.0 nozzle
Date	18/2/21
Activity	Print tests 1.0 nozzle
Date	19/2/21
Activity	Print tests 1.0 nozzle
Date	22/2/21
Activity	Print tests 1.0 nozzle
Date	24/2/21
Activity	Change to 1.2mm nozzle - print tests
Date	26/2/21
Activity	Print tests 1.2 nozzle
Date	2/3/21
Activity	Print tests 1.2 nozzle
Date	2/3/21
Activity	Print tests 1.2 nozzle / began design process
Date	10/3/21
Activity	Final layer test analysis, started painting parts
Date	12/3/21
Activity	Breakdown animatic into replacements [Appendix C.2]
Date	15/3/21
Activity	Logged all replacements required for film [Appendix C.3]
Date	18/3/21
Activity	Create version 1 of new witch design

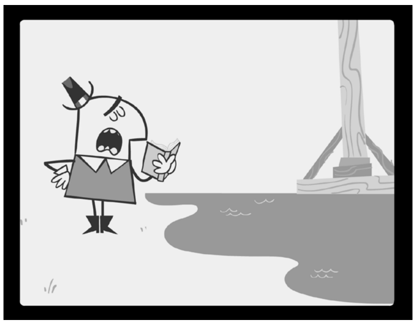
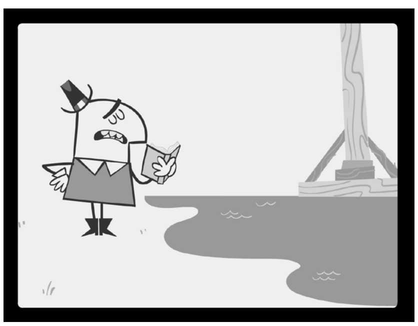
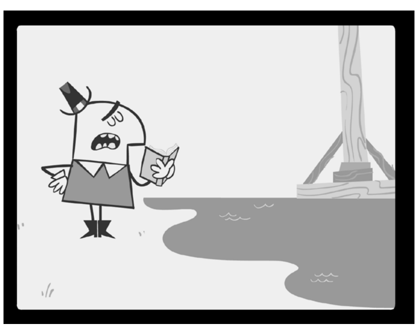
Date	18/3/21
Activity	Create version 1 of the new witch design - print. Scale Seems too large, did initial sketches to see the scale in the real world.
Date	23/3/21
Activity	Create version 2 of new witch design and version 1 of hunter design. Arranged printing meeting with Andy in fabrication for 13/04/2021 10:45 - 11:45.
Date	25/3/21
Activity	Tweaked design of Witch V2 and Hunter V1 and printed to test in the studio tomorrow. Booked time with Fabrication department for the 13/4/21. Head and body print is good creates nice snug fit which feel nice but may be an issue when making small alteration when animation. Slight elephant foot on both top of body and base of heads creates lock. Also, back and overlap of body could be increased to not effect animation.
Date	26/3/21
Activity	Test prints and painting tests under camera. Bought materials for limb and mouth construction.
Time	
Date	31/3/21
Activity	Discussing with Fabio test printing of puppet parts hats, eyes, mouth, and shoes. Send over form set up for printing will take 5 hours - pick up tomorrow.
Time	1 hr
Date	1/4/21
Activity	Collected prints from Fabio CFPR.
Time	30min

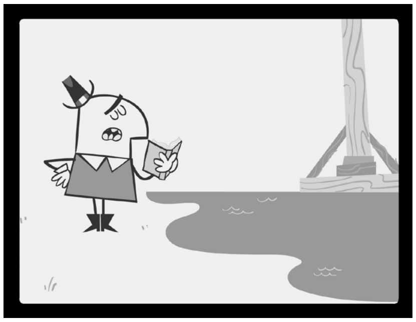
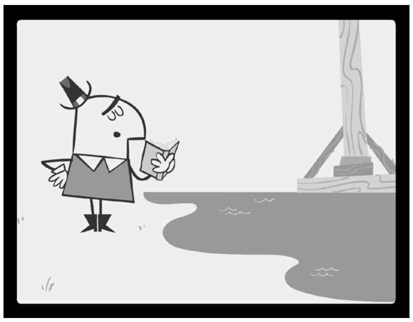
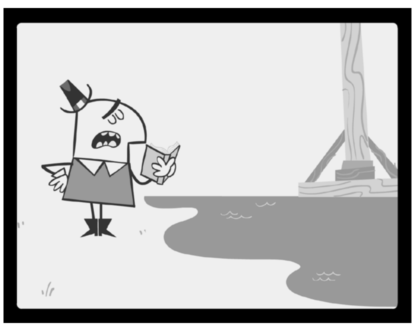
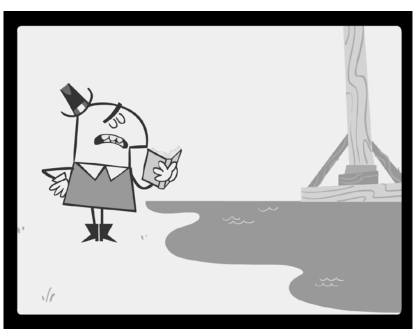
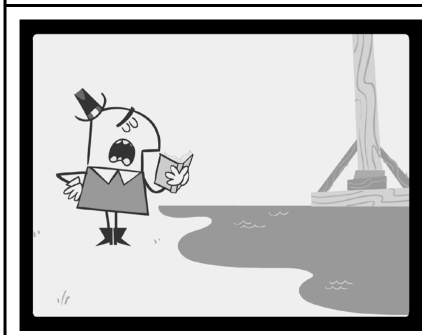
Date	6/4/21
Activity	modelling all parts to be printed
Time	4hrs
Date	7/4/21
Activity	modelling all parts to be printed
Time	4hrs
Date	8/4/21
Activity	modelling all parts to be printed
Time	4hrs
Date	9/4/21
Activity	modelling all parts to be printed
Time	4hrs
Date	12/4/21
Activity	Modelling all parts to be printed, prepare files for printing set up for labs.
Time	6hrs
Date	13/4/21
Activity	re-scale hands and shoes to match scale image. Print with fabrication into machines. (7hrs? print time) to pick up tomorrow for post processing. Begin creating limbs and sanding and painting prints from Fabio. Andy suggested cleaning but not curing to increase strength.
Time	7hrs
Date	14/4/21
Activity	Pick up prints. The larger of the sets had some abnormality to surface lines, scratched and divots, also both sets are very sticky, and the surface is soft and scratches away, decided to cure one set to see if it helps and try a second clean for the larger more floured set. Curing has resolved stickiness. So, the second larger set is also light cured. After reviewing this some prints have also merged on the bed, so offered a free reprint of the worst affected piece of the second set on the printer that gave the better-quality finish. Have noticed w_hand_smear is wrong scale, need re print. Also, that witch hat needs to be reversed for the second half of the film. Will also look into modeling the bondage for both characters. Removed supports, sanding, and paint test new prints.

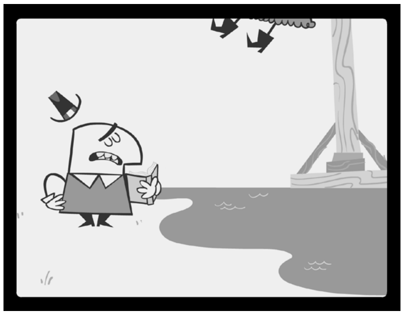
Time	8 hrs (2hrs print prep/analysis/troubleshooting, re-print = 4.5 hrs, curing = 15min +5min warm up, 5hrs sanding and painting)
Date	15/4/21
Activity	Modeling for FDM body and headsets, re-scale Witch hand smear and flip hat. Begging modeling rope for SLA. Made alterations to body increased depth of details collars/buttons and increased limb holes to 5ml. Also altering base of head to a more exaggerated chamfer to help with elephant footing.
Time	6hrs
Date	16/4/21
Activity	Painting all hands, eyes, mouths, hats, and shoes from 14/4/21. Also recording of process time lapses. Finished limbs.
Time	6hrs
Date	17/4/21
Activity	Altering print settings to try and reduce elephant foot on parts more. Recorded video of FDM printing. Completed rope model and other Witch mouth parts, and prepared file for reverse witch hand, larger smear, rope and other Witch mouth parts.
Date	19/4/21
Activity	Printed rope, hat, mouths. Finished painting base for SLA files. Also recorded SLA printing and time lapse of sanding. Sanding, prep, and painting of previous batch of prints.
Date	20/4/21
Activity	Printed new FDM heads, adjusted Hunters heads to aid print layers. Update log. Added line 1 mm line across neck of collar on both Hunter and Witch bodies to create line work and help print process. Also reduce depth two 1mm.
Date	21/4/21
Activity	Back painting detail into all hands, and printing of new models from 19/4/21- rope, hat mouths. Sanding and paint test of new heads. Decided to not spend too much as does not create the desired look, also using shoe polish to enhance FDM grain. Will paint side to create depth and use milliput for inside mouth and teeth for Witch.
Date	26/4/21
Activity	Print remainder of heads, reprint bodies with adjustments. If possible, print multiples. Added teeth to Witch heads

Date	27/4/21
Activity	Shoot test in stop-motion set up booth, print smear fins for hunter smear. Add paper detail to eyes. Paint test
Date	28/4/21
Activity	Paint all heads and fins from print yesterday.
Time	6hr
Date	3/5/21
Activity	Paper cut for clouds, water, book. Back rope, background, pupils.
Time	2hrs
Date	4/5/21
Activity	Set up lighting, re-made background elements to scale, test shot.
Time	2hrs
Date	5/5/21
Activity	Shot the first half of the film all well and looking good.
Time	7hrs
Date	6/5/21
Activity	Shot the second half of the film, all well and looking good.
Time	6hrs
Date	7/5/21
Activity	Filmed second pass elements (water) all complete.
Time	1hr
Date	16/5/21
Activity	Editing and sound by Ben, creating title cards.
Time	5hr
Date	17/5/21
Activity	Questioners, film and making are sent out to participants and reviewers.
Time	1hr

Appendices C.2 - Animatic Breakdown.

	HUNTER						WITCH				
	HEAD	MOUTH	HANDS	HAT	EYES	BROW	HEAD	MOUTH	HANDS	EYES	OTHER
	1	1	L/ HIP R/ BOOK	1	1	1					
	“	2	“	“	“						
		3									

		4									
		5									
		3									
		2									
		1									

	2	2									
	2	2				2					
	1	6		2		3					
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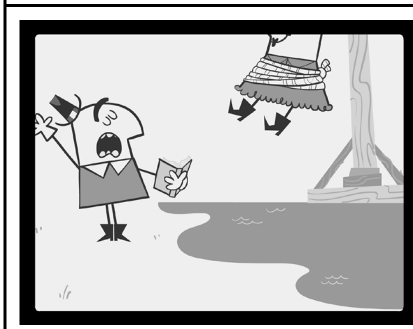		1									

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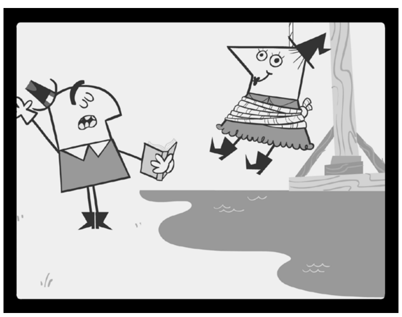		4									
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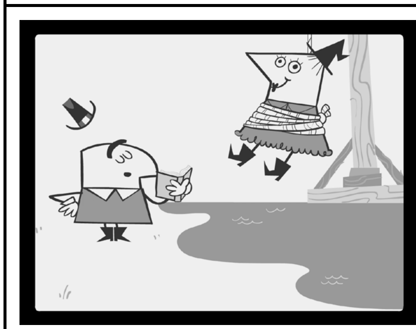
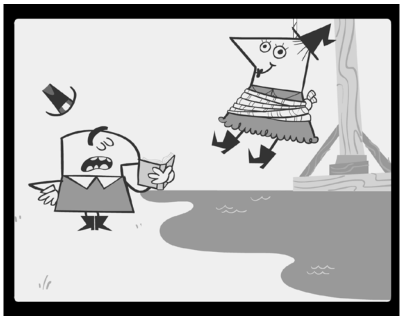
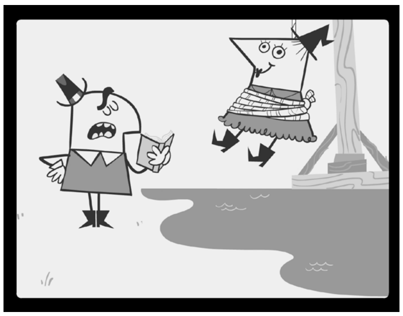
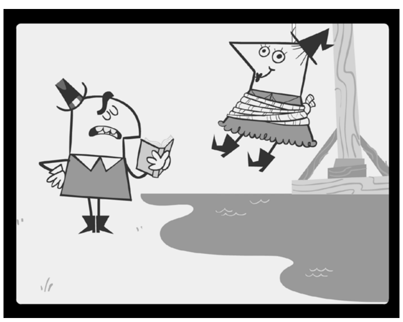
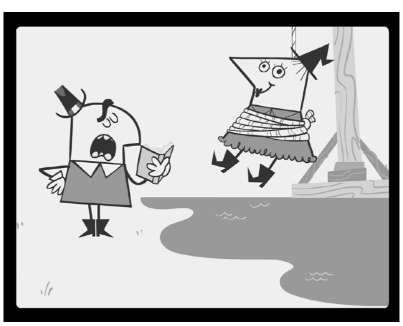
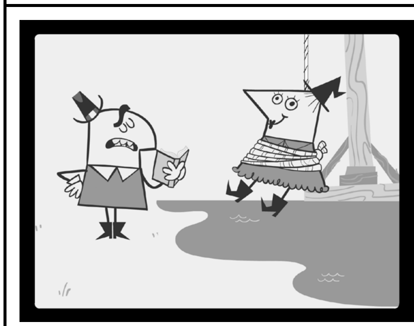
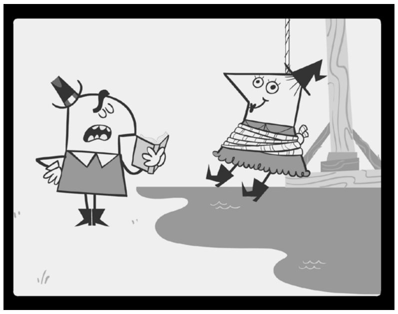
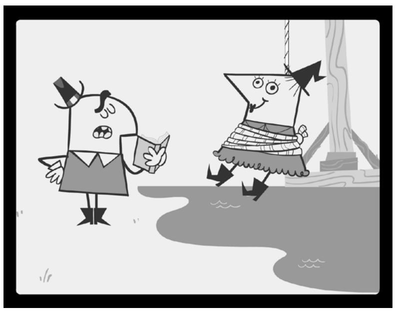
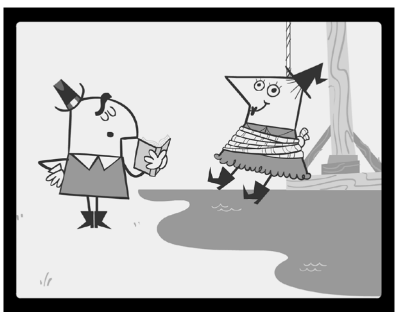
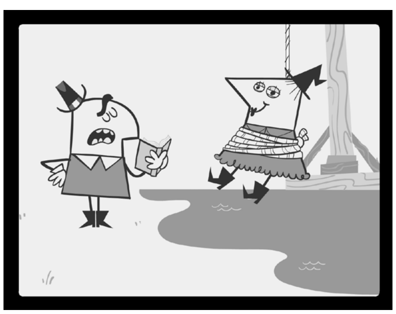
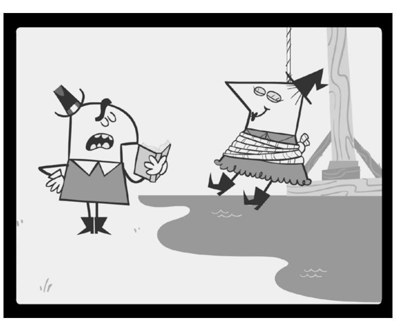
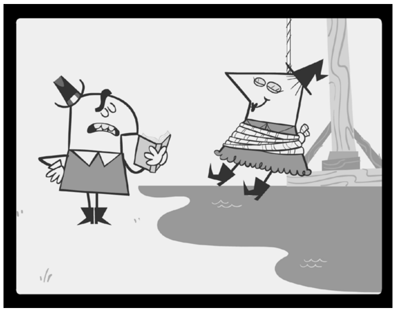
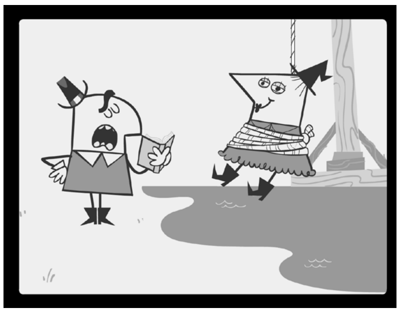
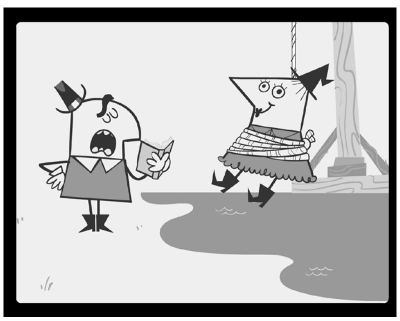
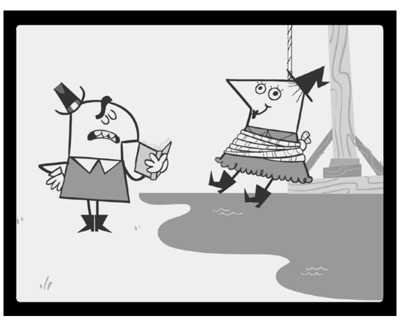
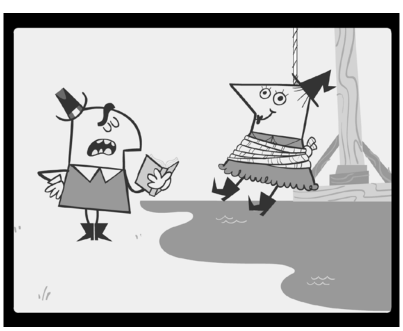
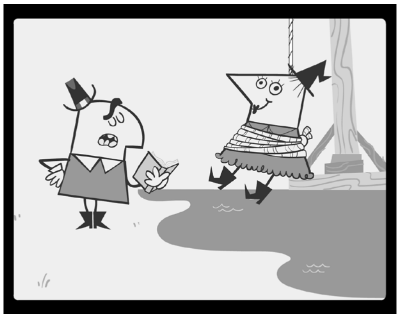
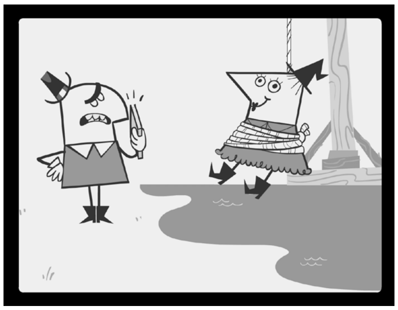
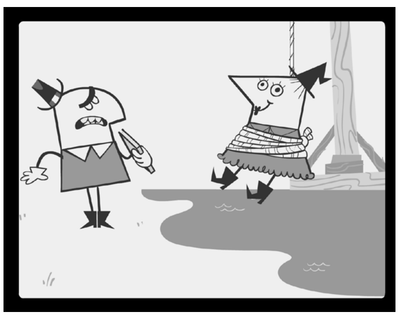
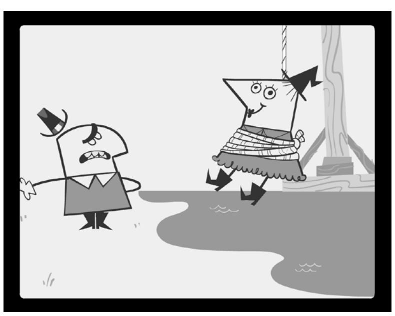
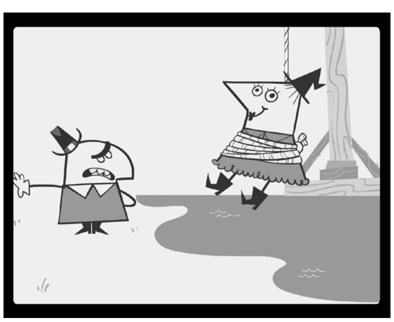
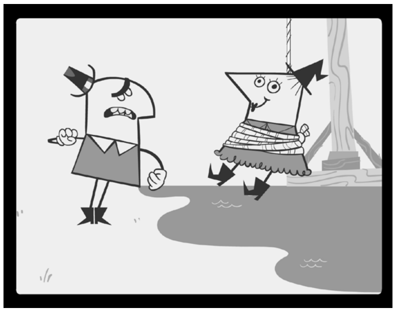
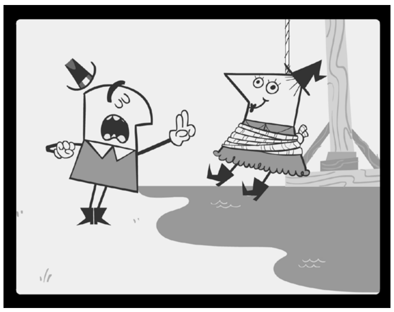
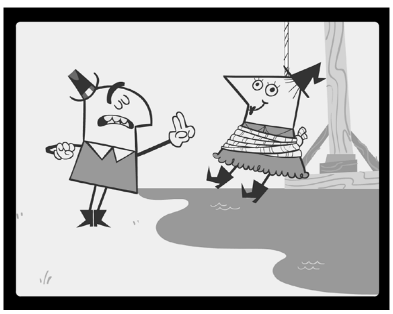
	2		L/ HIP R/ BOOK								

		3									
	1	3				4					
		2									
		1									
		2									

		1									
		4									
		5									
		3								2	
		3								3	

		2								3	
		1								2	
		1								1	
		2									
		3									

		4									
		2	L/ HIP R/ CLO SED			2					
		2	L/ OPEN R/ CLO SED								
	2		L/ OPEN								
											

	1		L/ CLO SED R/ CLO SED								
		1	L/ CLO SED R/ FIN GER			3					
		2									
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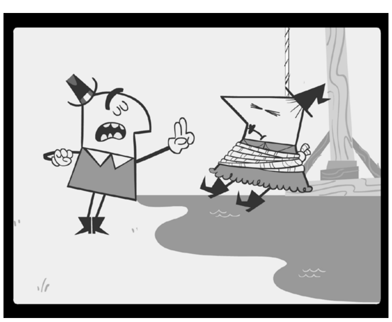
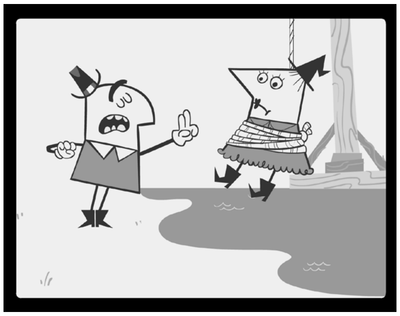
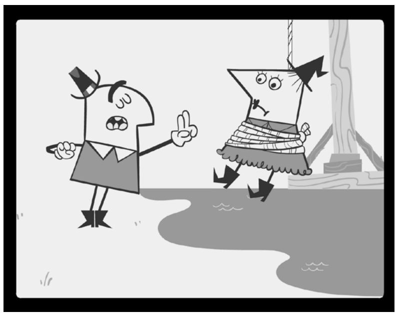
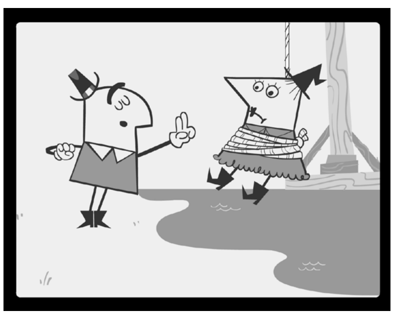
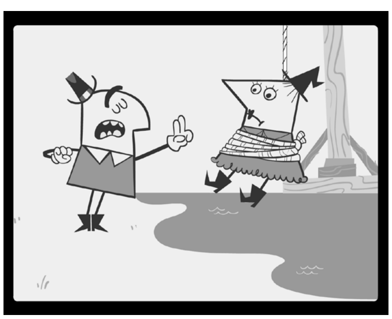
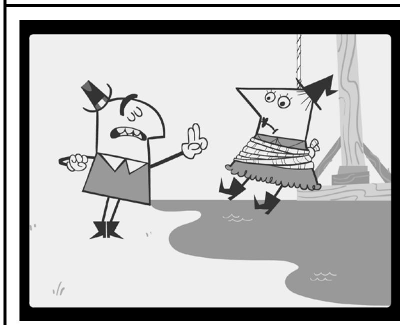
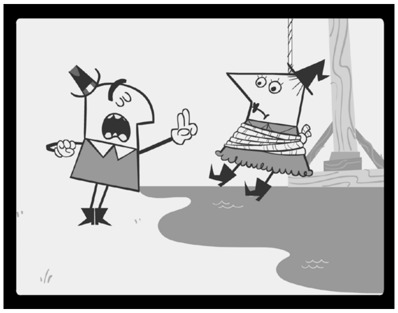
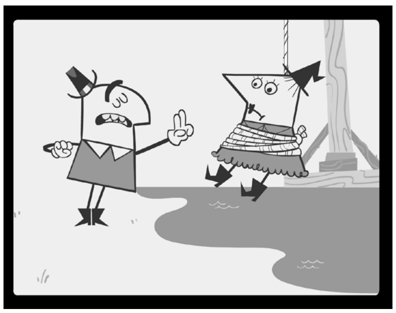
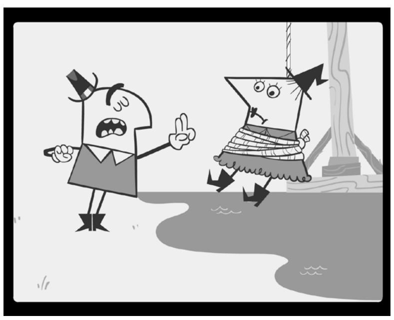
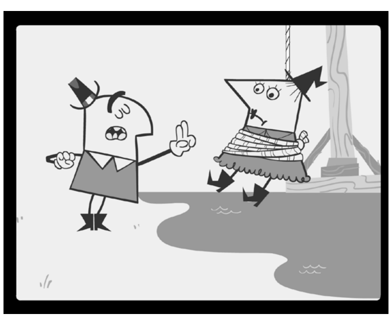
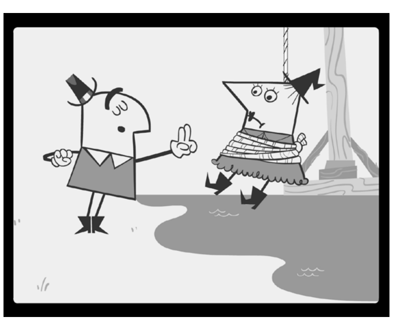
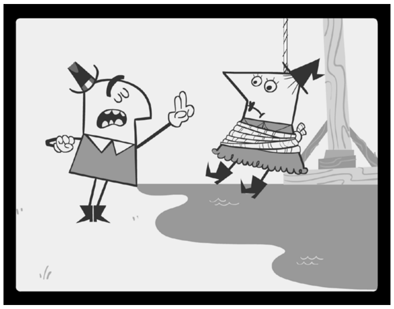
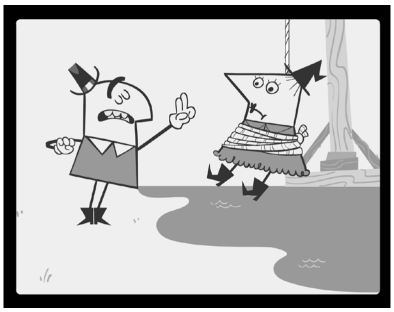
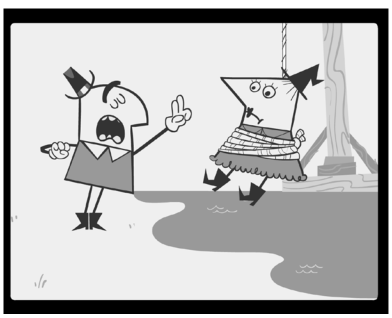
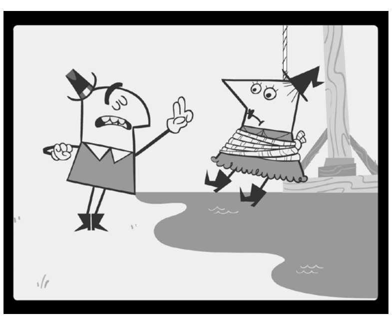
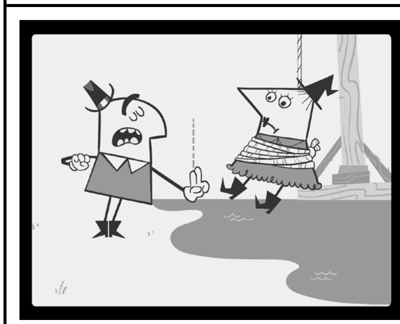
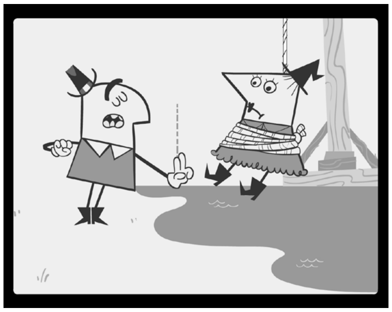
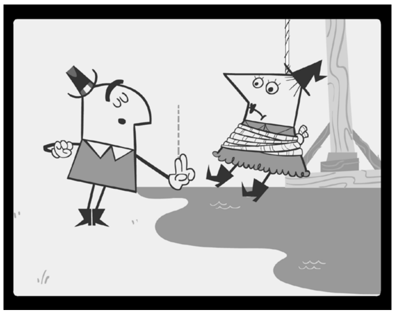
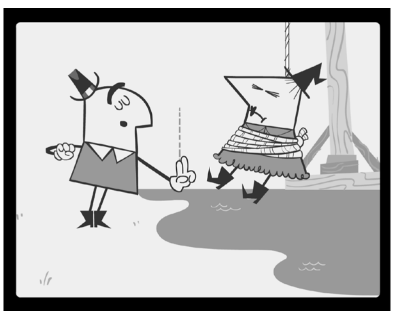
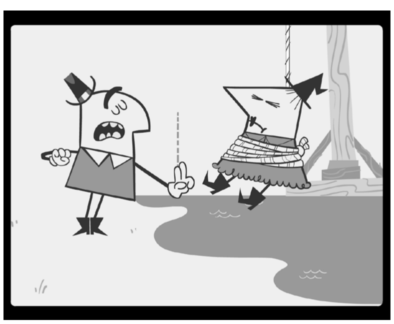
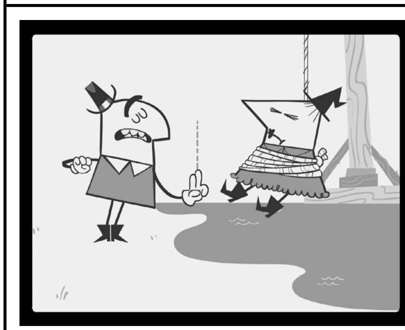
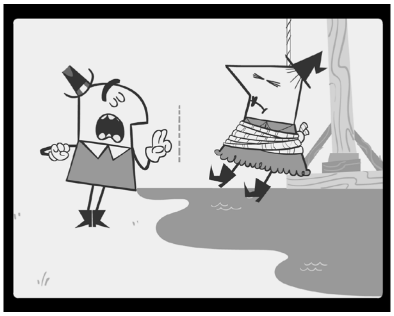
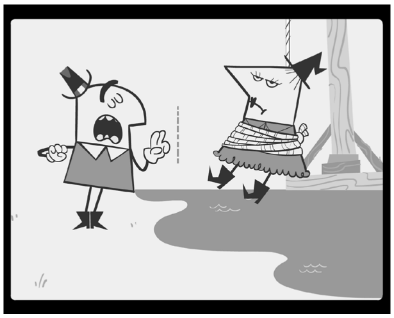
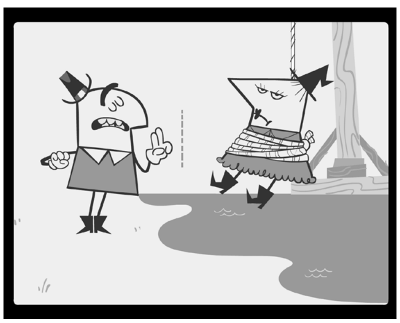
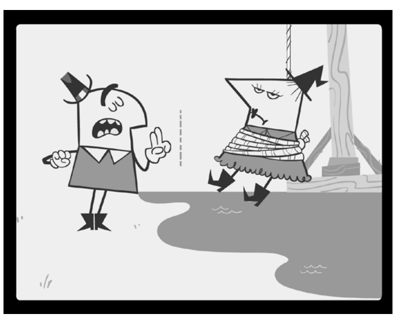
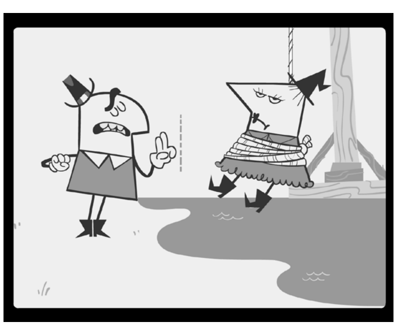
		3									

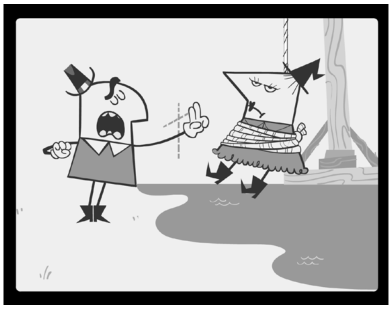
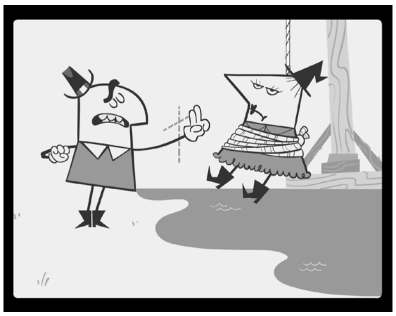
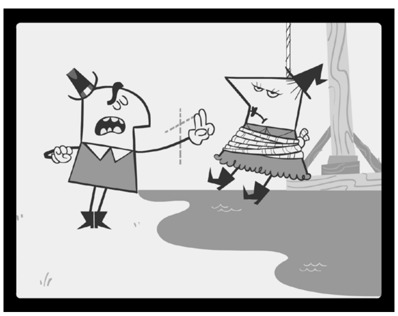
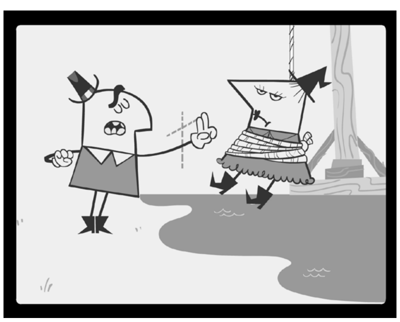
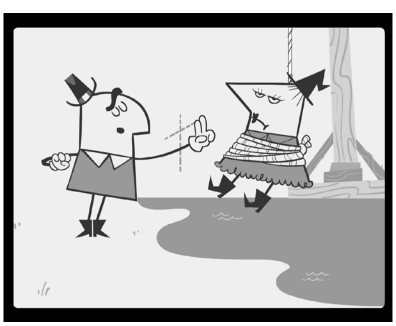
										1	
		4									
		5									
		3									
		2									

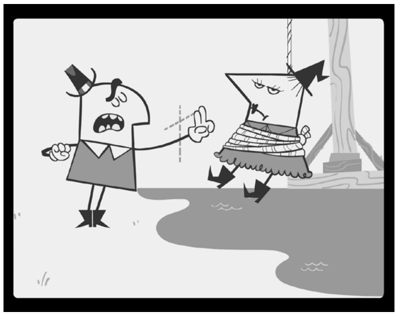
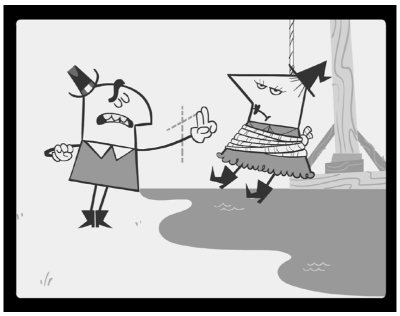
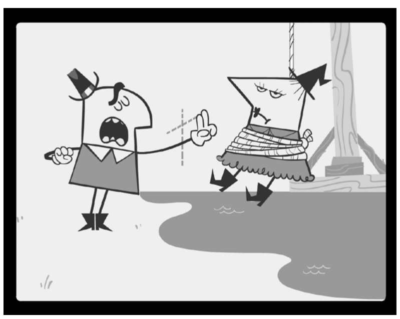
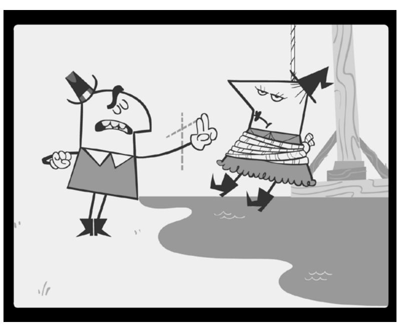
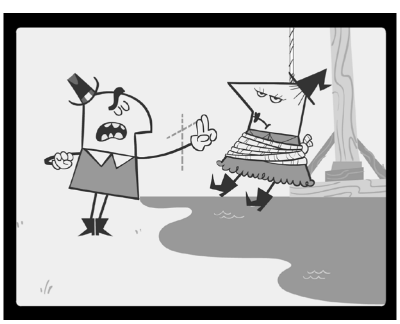
		1									
		2									
		3									
		4									
		5									

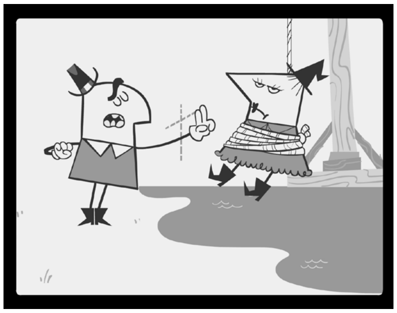
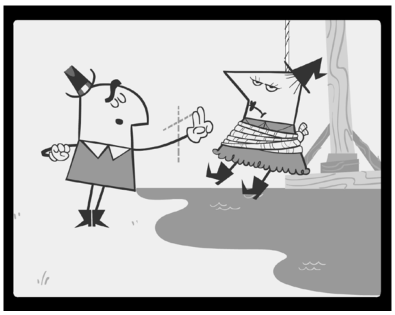
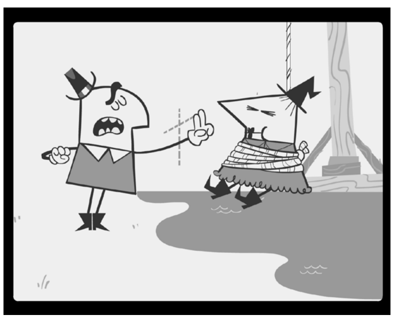
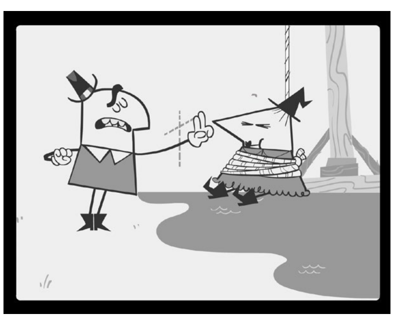
		3									
		2									
		1									
		2									
		3									

		4									
		5									
										4	
		3									
		2									

		1									
										5	
		2									
		3									
		2				4					

		1									
		2									
		3									
		4									
		5									

		3									
		2									
		1									
		2									
		3									

		4									
		5									
		3					2	3		4	
		2					3				
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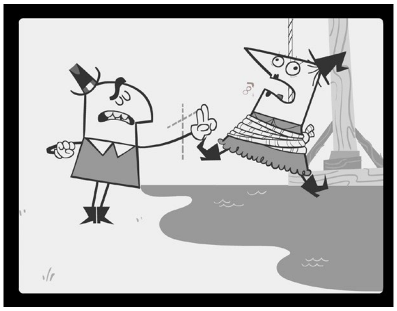
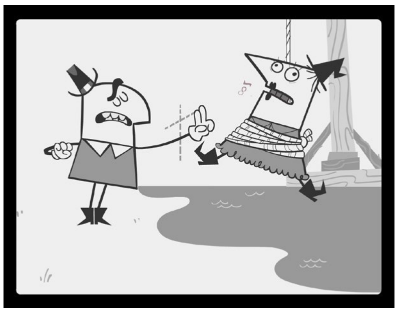
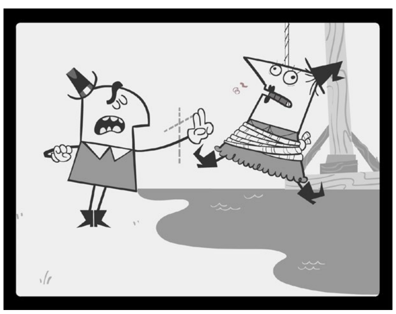
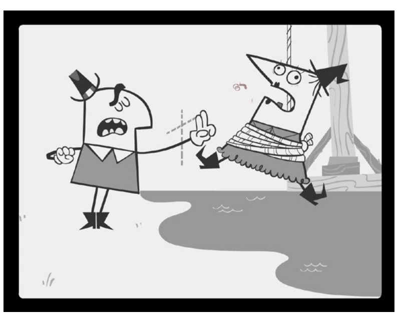
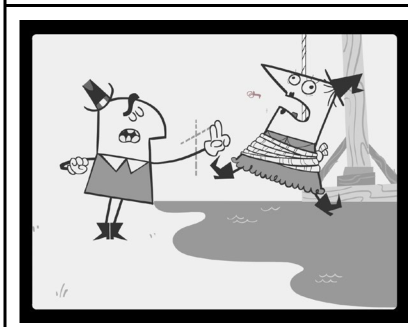
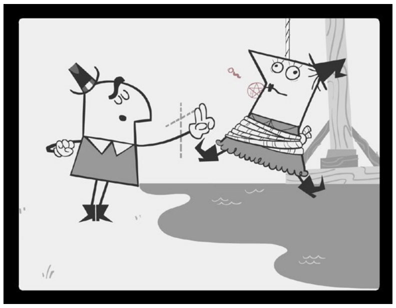
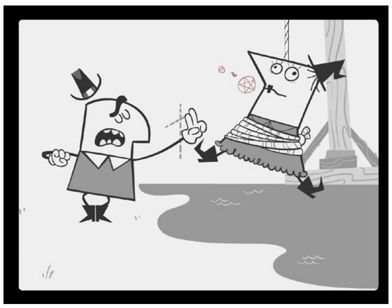
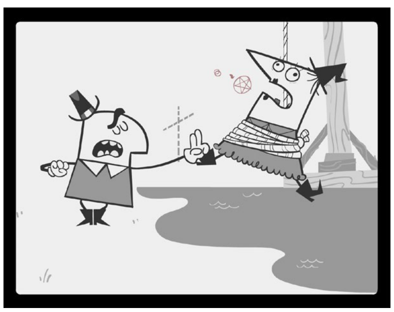
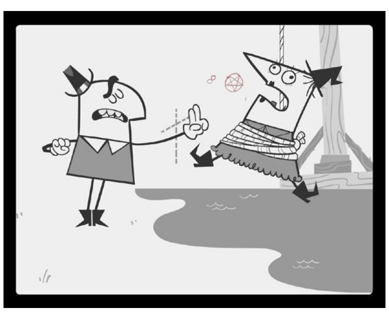
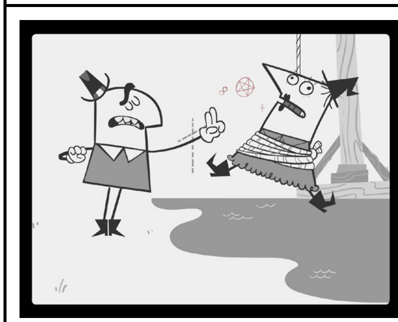
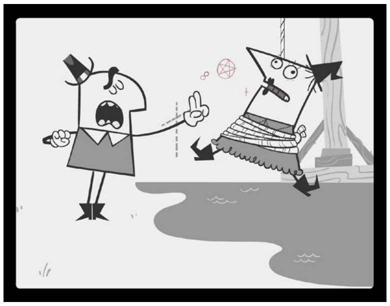
		2									
							5				
		3									
							4				
		4									

		5					6	5			
		3									
							4	4			
		2									
							5				

		1									
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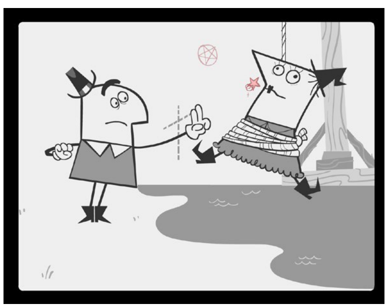							6	5			
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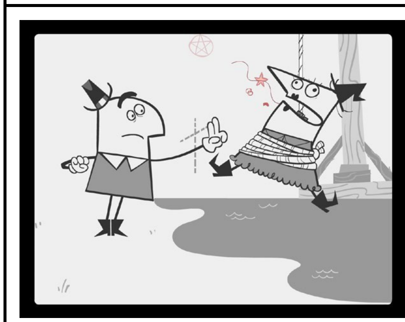
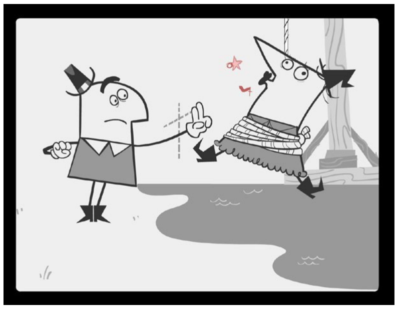
							8				

							9	6			
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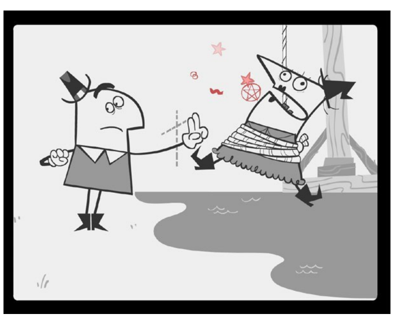
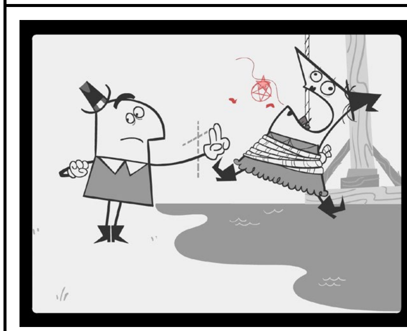
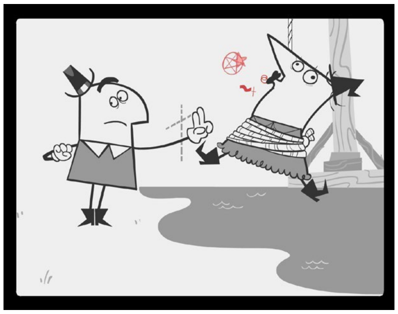
							8				
							7				

							9	6			
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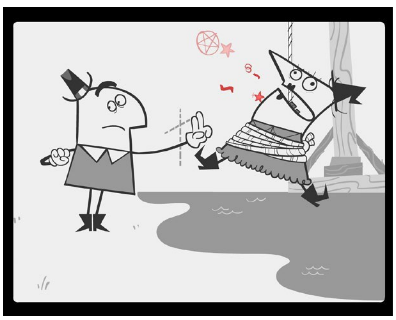							8				
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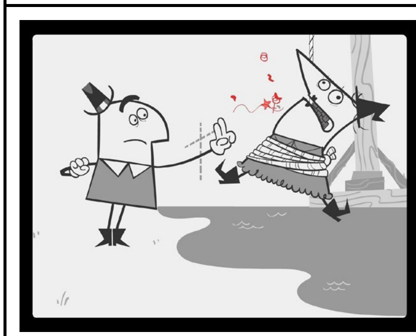
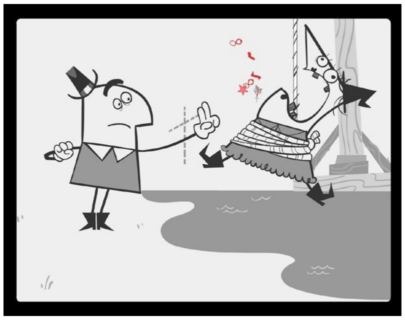
							10				

							11				
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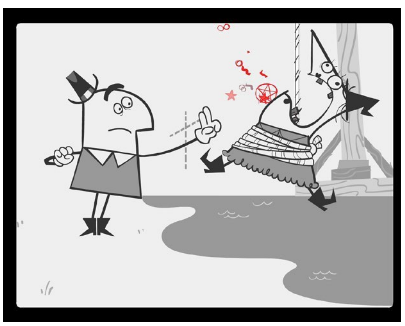							11				
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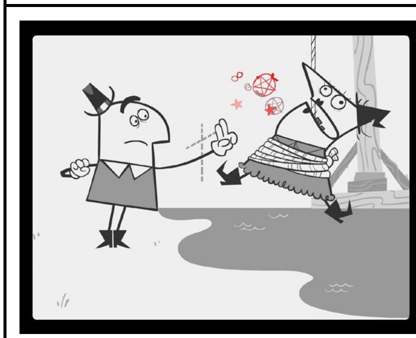
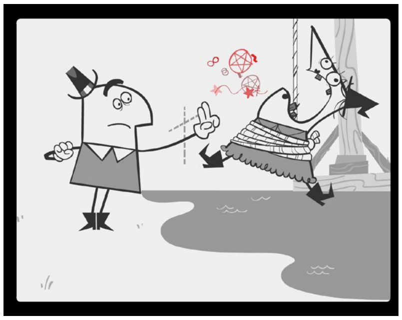
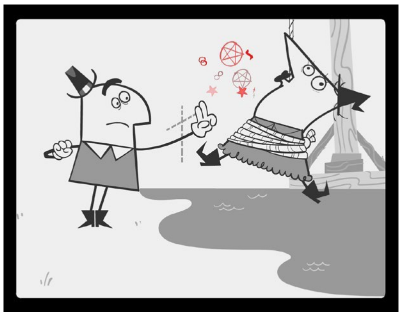
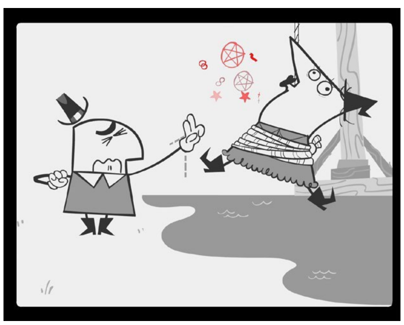
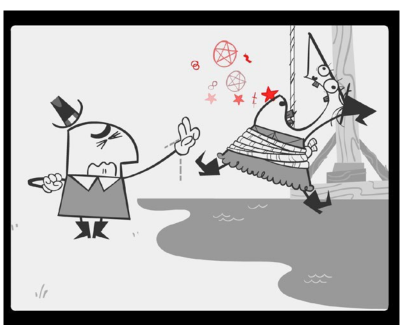
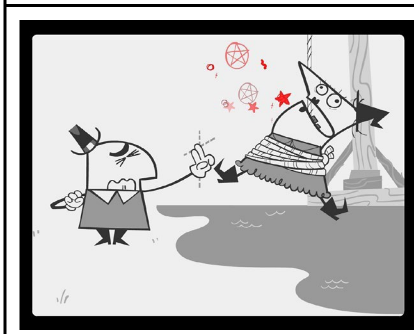
							8				

							1 1				
							9	6			
	2	7			3	2					
							1 1	4			
							8				

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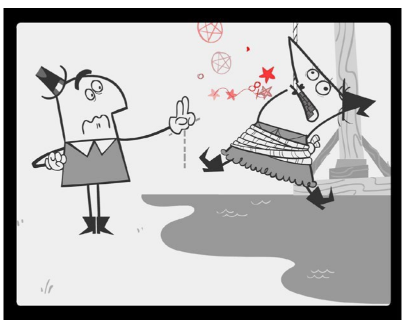							13				
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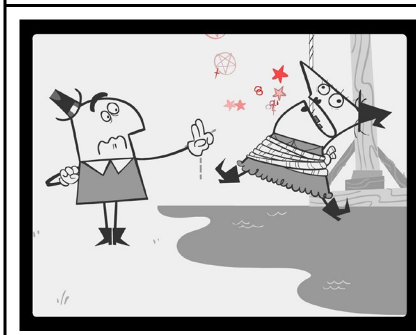							8				

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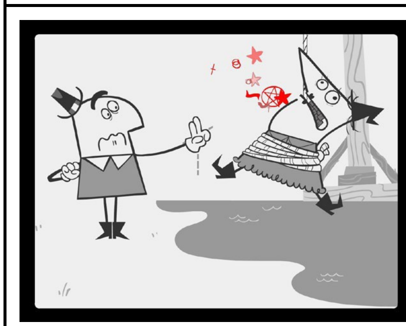
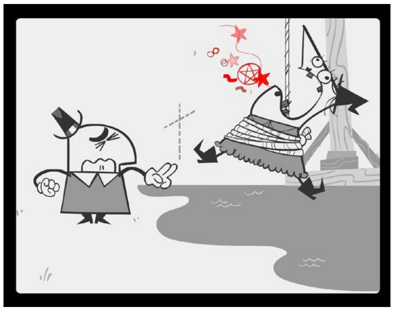
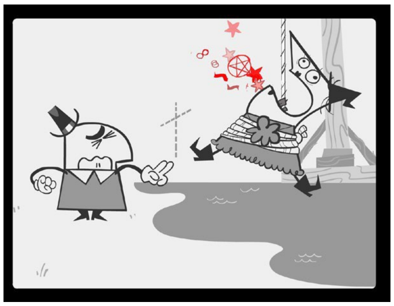
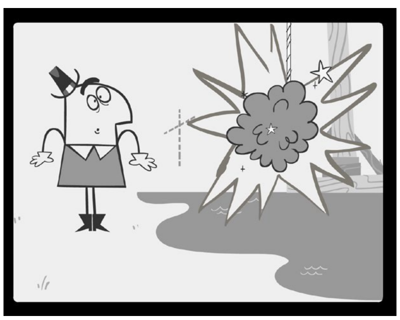
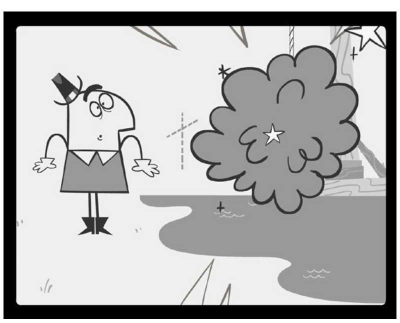
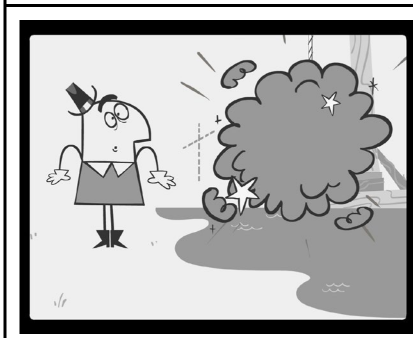
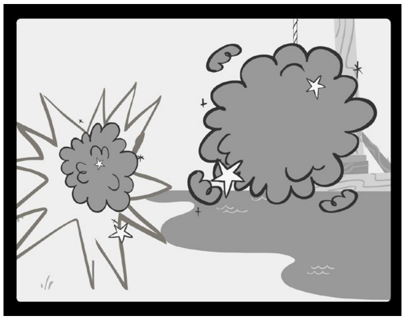
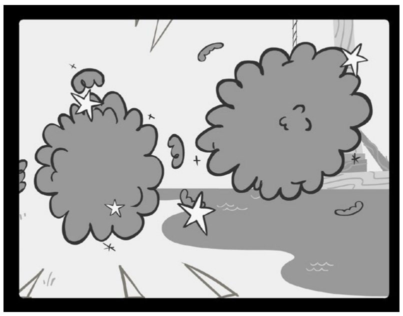
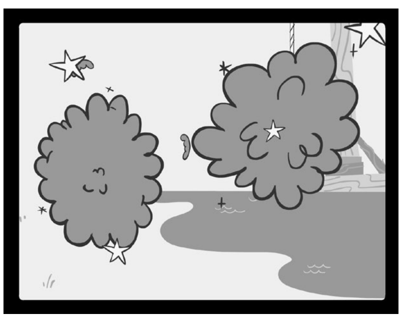
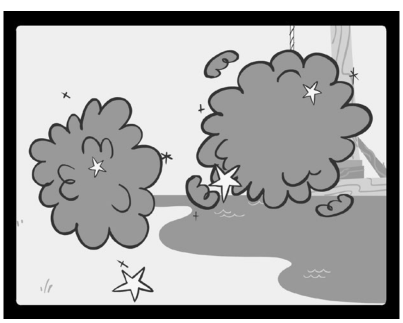
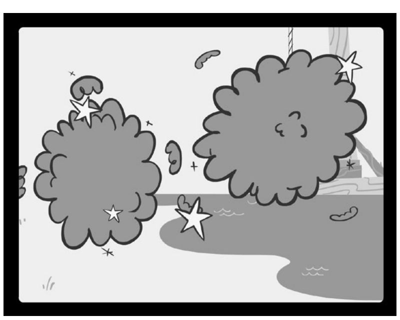
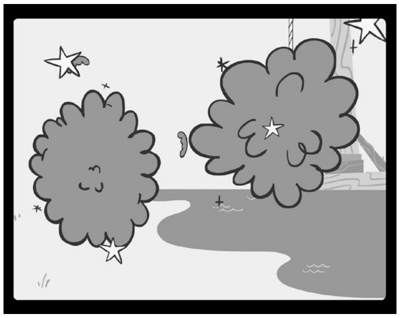
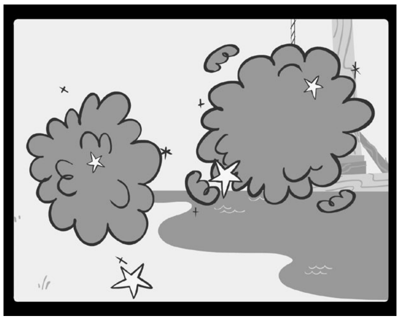
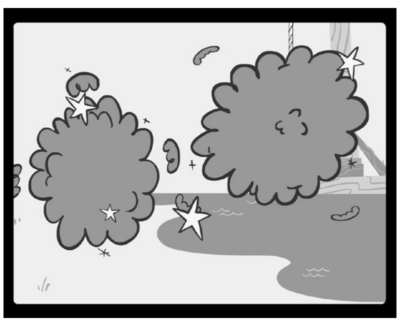
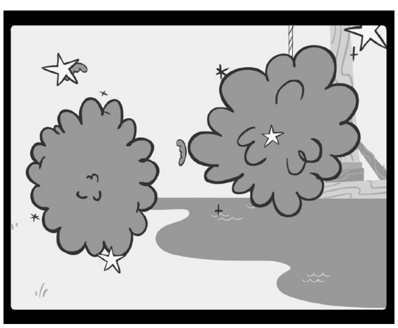
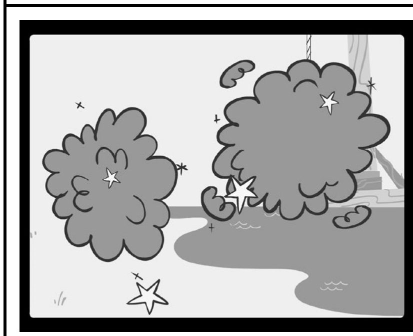
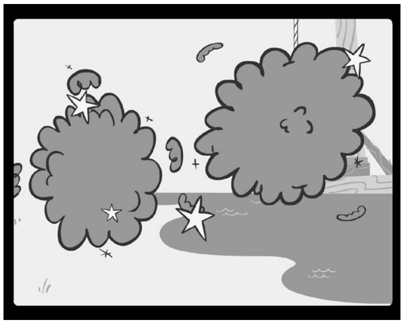
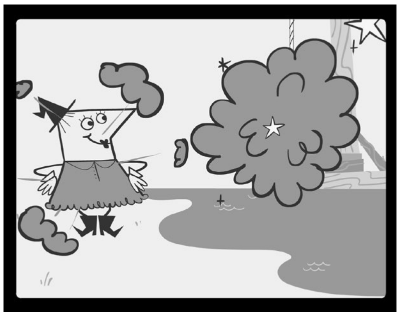
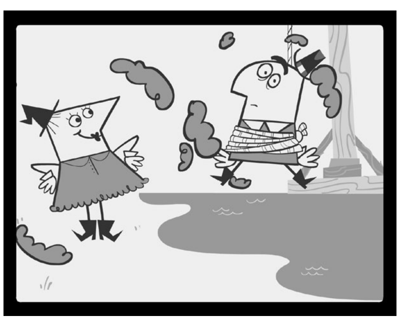
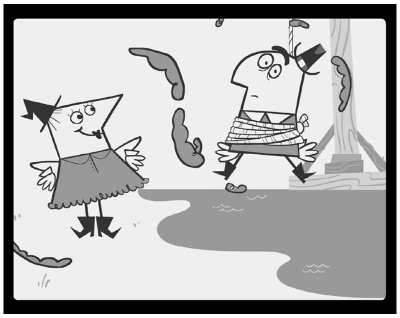
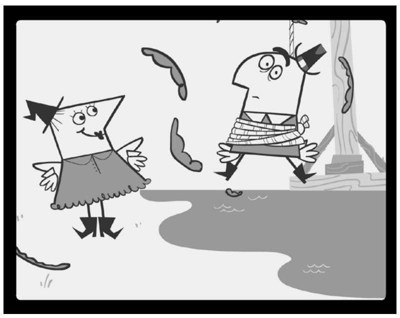
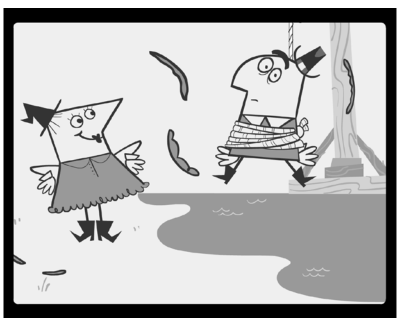
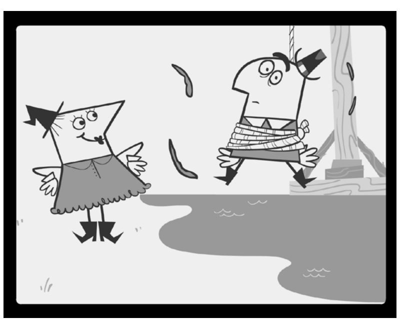
							10	4			

	2				3	2	1 1				
							1 2				1
		8	L- open r-open		4	3					2
											3
					4	3					4 (8, 9, 10)

											2,4 (8, 9, 10)
											5,6 (8, 9, 10, 11, 12)
											6,7 (11, 12)
											3,4 (8, 9, 10)
											4,6 (8, 9, 10, 11, 12)

											6,7 (11, 12)
											3,4 (8, 9, 10)
											4,6 (8, 9, 10, 11, 12)
											6,7 (11, 12)
											3,4 (8, 9, 10)

											4,6 (8, 9, 10, 11, 12)
							1 3	1	L-hip R-hip	1	3 (12, 13, 14, 15)
											4 (8, 9, 10, 12, 13, 14, 15)
		9	L - Hip R - Hip		4	3					8, 9, 10, 12, 13, 14, 15
											8, 9, 10, 12, 13, 14, 15

											8, 9, 10, 12, 13, 14, 15
											13, 14, 15
											
											
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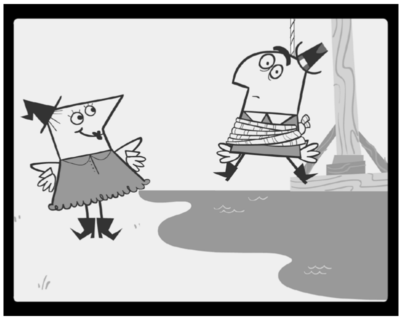
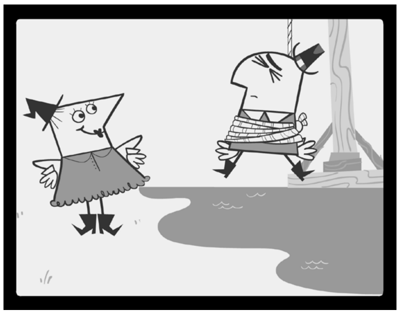
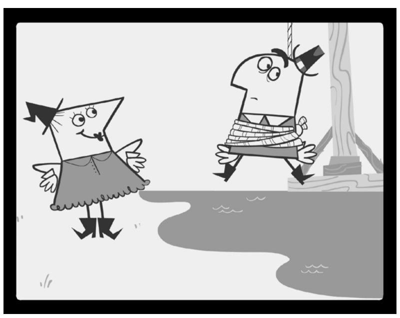
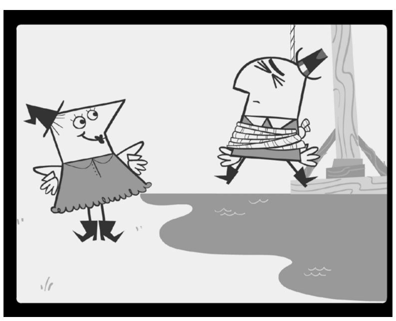
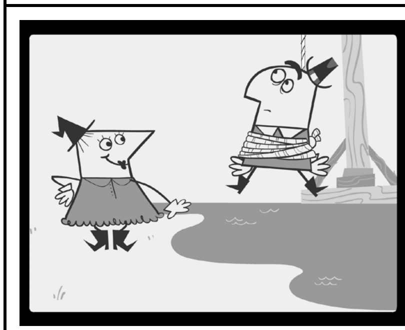
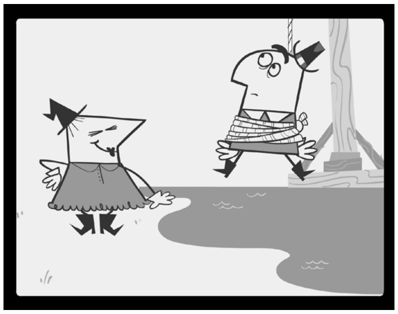
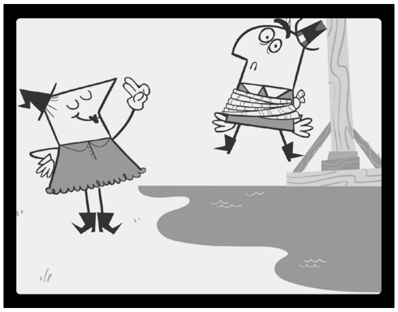
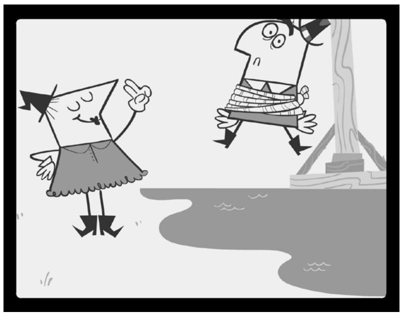
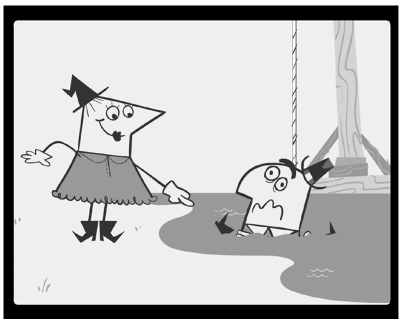
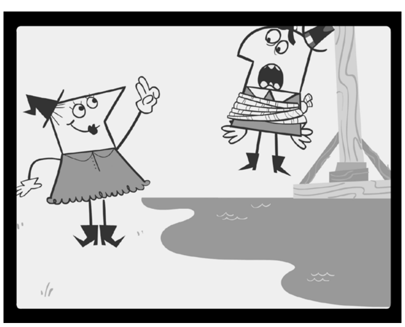
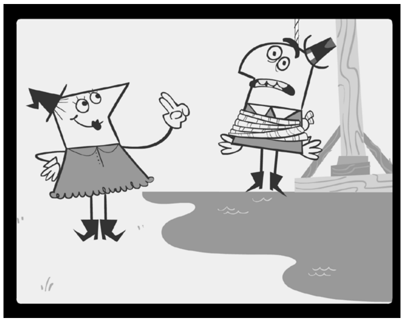
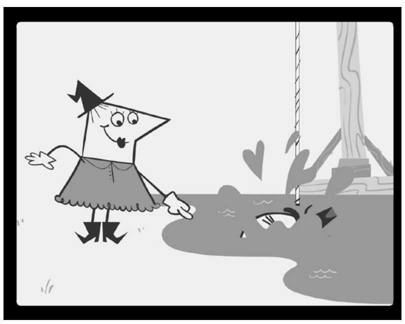
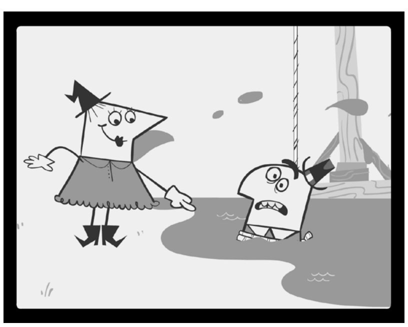
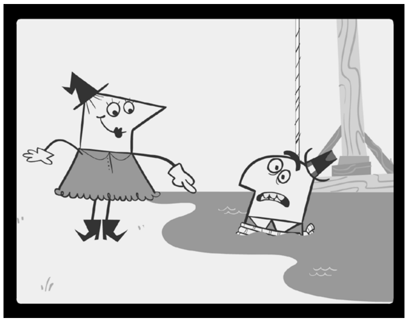
											
											
											
						2					
						3					

									L-hip E-open	4	
									L-hip R-hip		
									L-hip R-finger- bent	6	
									L-hip R-finger		
						2			L-hip R-finger- bent		

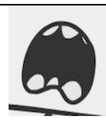
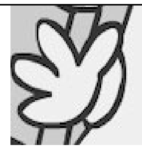
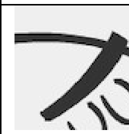
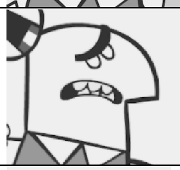
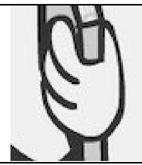
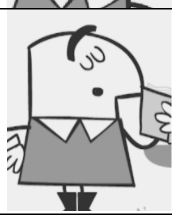
		1 0				3			L-hip R-finger		
											
	3					4			L-open R-finger		
	1										W A T E R D R O P S

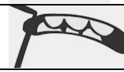
						2				1	W A T E R D R O P S
		7				3					
									L/ OPEN R/ SMEAR		
		1							L/ HIP R/ FINGER		

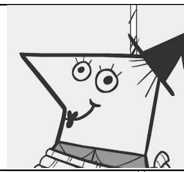
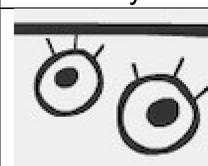
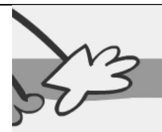
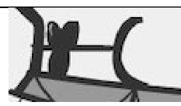
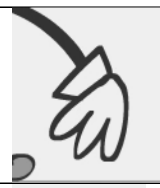
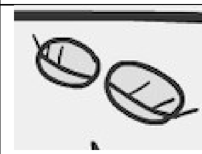
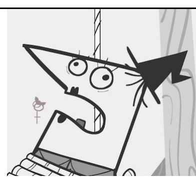
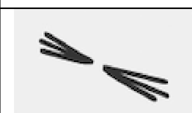
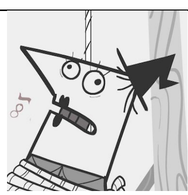
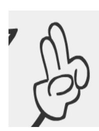
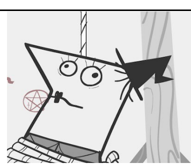
		1 1									
	3					4					
	1					3					W A T E R D R O P S
											“

											
								7			
	3	3				4					
	1					3					W A T E R D R O P S

Appendices C.3 – Replacement Breakdown.

HUNTER							
	Head	Mouth	Left hand	Right hand	Hat	Eye	Eyebrow
1							
2							
3							
4							
5							
6							
7							
8							
9							

10							
11							

WITCH					
	Head	Mouth	Left hand	Right hand	Eyes
1					
2					
3					
4					
5				 	
6					
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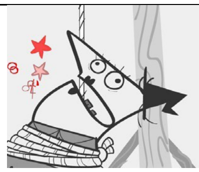
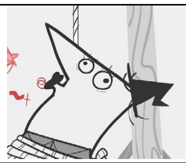
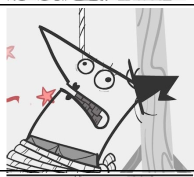
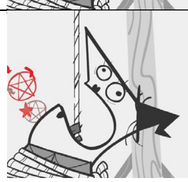
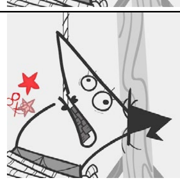
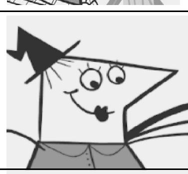
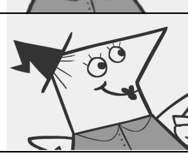
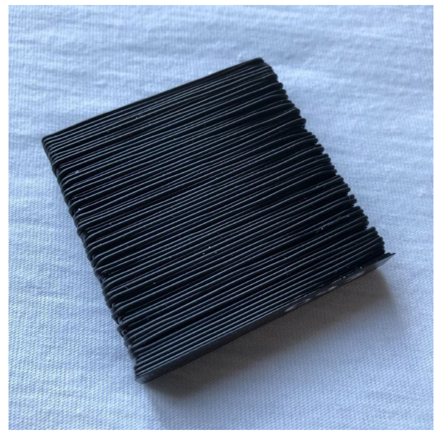
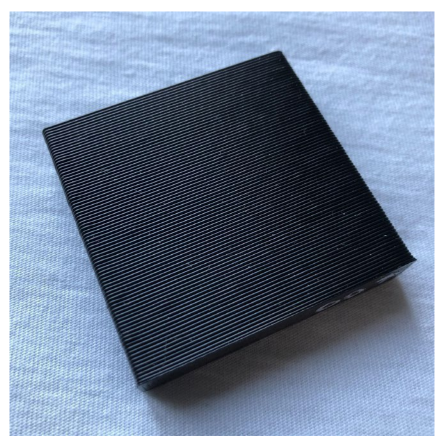
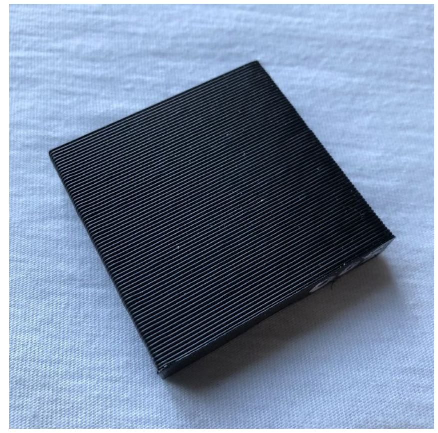
8					
9					
10					
11					
12					
13					
14					
15					

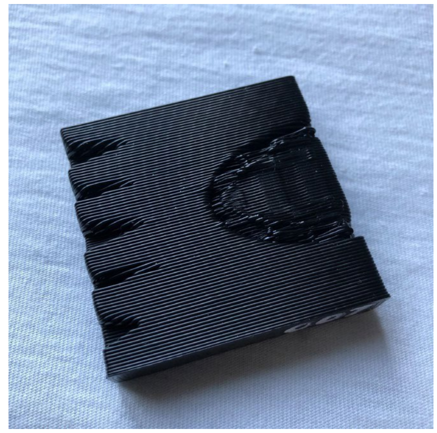
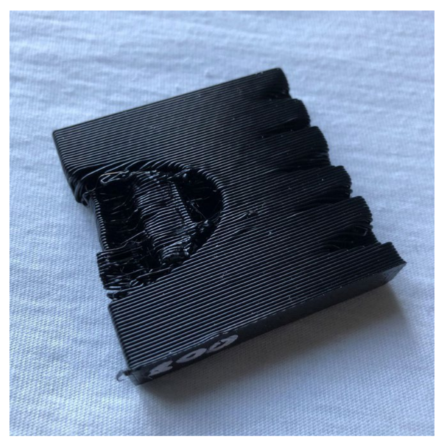
Appendices C.4 – Nozzle Layer Height Analysis Log

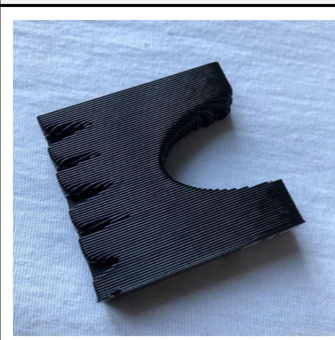
Creality Ender-3 V2 0.8 Nozzle	Generic PLA 0.8 Nozzle
Wall thickness	1.6mm
Top/Bottom Layer	4
Travel Enable retraction	True
Cooling enable Print cooling	True
Fan Speed	100%

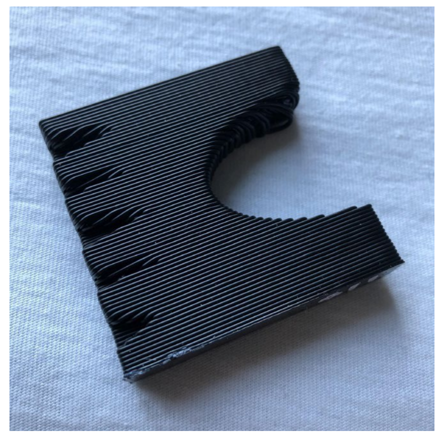
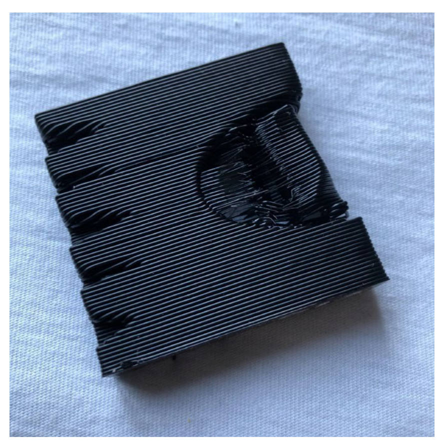
Test no	001	ANALYSIS	IMAGE
Nozzle	0.8	Some bulging on the corner [back right], some uneven layers perhaps due to cooling. Not unhappy but may prove an issue for maintaining consistency. Some cracking can be heard if stress is put on parts. Going to try increasing layer height just to see, if bad result will return to other settings such as speed, infill and wall count	
file	test_v1		
Layer height - Top/Bottom thickness	0.6/ 2.12		
Temp print/ bed	205/60		
Speed mm/s	40		
Infill density/pattern	20%/ cubic		
Wall count	4		
Test no	**002**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Some bulging on the corner [back right], layers are more uneven. Cracking can be heard if stress put on parts will likely split may be worth increasing infill. Layers are still adhering to one another so going to increase layer height one more time to	
file	test_v1		
Layer height - Top/Bottom thickness	**0.7/2.42**		
Temp print/ bed	205/60		

Speed mm/s	40	see how far it can go, then work backwards to see if improvements can be made.	
Infill density/pattern	20%/ cubic		
Wall count	4		
Test no	**003**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Generally, layers are very loose, don't think we can push this further, minimal pressure leads to cracking, would break easily. Next step is to reduce layer height and fine tune some settings: Reduce speed to help adhesion. Increase infill to add strength Reduce wall count to see if this aids in strength, print speed and finish.	
file	test_v1		
Layer height - Top/Bottom thickness	**0.8/2.72**		
Temp print/ bed	205/60		
Speed mm/s	40		
Infill density/pattern	20%/ cubic		
Wall count	4		
Test no	**004**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Quality perfect, no layer lines. Strong and clean. Next steps try same settings with 0.7 layer height	
file	test_v1		
Layer height - Top/Bottom thickness	**0.6/2.12**		
Temp print/ bed	205/60		
Speed mm/s	**30**		
Infill density/patt	**50%**/cubic		

ern			
Wall count	**2**		
Test no	**005**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Quality similarly perfect, minor change in layer height successful. 1 slight floor near top. Next steps try the same settings with 0.8 layer height.	
file	test_v1		
Layer height - Top/Bottom thickness	**0.7**		
Temp print/ bed	205/60		
Speed mm/s	30		
Infill density/patt ern	50%/cubi c		
Wall count	2		
Test no	**006**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Noticeable change in quality but still strong and relatively clean few little notches inside profile. I don't believe I can go further than the nozzle width - will check with technicians and online. Next steps: Move on to file test _v2 which has some minor details on it. added support 20 density/ line pattern for the cut-out shape on the right. But using a support block for the details on the left of models.	
file	test_v1		
Layer height - Top/Bottom thickness	**0.8/2.42**		
Temp print/ bed	205/60		
Speed mm/s	30		
Infill density/patt ern	50%/cubi c		
Wall count	2		
Test no	**007**	**ANALYSIS**	**IMAGE**

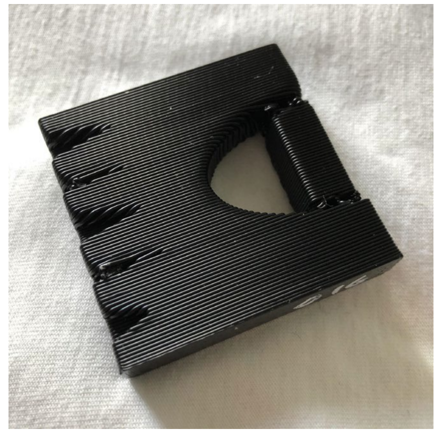
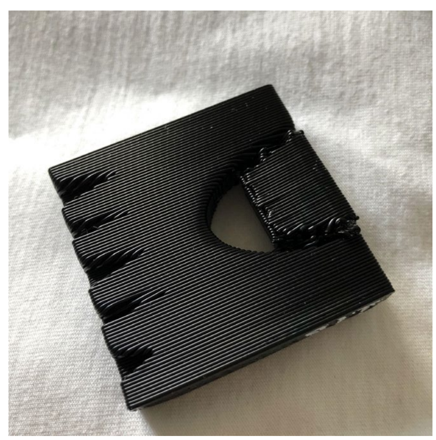
Nozzle	0.8	Quality good, cut out detail has worked well with minor over extrusion on top, the support however for the cut out on the right has fused entirely. The support type needs changing/reducing Reduce support interface thickened from 2.4 to 1mm. Take support wall line count to from 1 to 0 and support density to 10%	
file	**test_v2**		
Layer height - Top/Bottom thickness	**0.6/2.12**		
Temp print/ bed	205/60		
Speed mm/s	30		
Infill density/pattern	50%/cubic		
Wall count	2		
Support; Overhand angle 33 Patter: lines Wall line count: 1 Density 20 Interface thickness: 2.4			
Test no	**008**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Support is low and still sticking heavily to the body. Also reversed build creates detailed decreased quality. Next steps: I'm going to try it in its original orientation and with no supports.	
file	test_v2		
Layer height -Top/ Bottom thickness	0.6/2.12		
Temp print/ bed	205/60		
Speed mm/s	30		
Infill density/ pattern	50%/cubic		

Wall count	2		
Support; **Overhand angle 33** **Patter: lines** **Wall line count: 0** **Density 10** **Interface thickness: 1**			
Orientation	**reversed**		
Test no	**009**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Surprisingly not bad some minor issue on the first few layers- and struggled when at the top of the cut-out shape - perhaps reducing the speed would help?	
file	test_v2		
Layer height - Top/Bottom thickness	0.6/2.12		
Temp print/ bed	205/60		
Speed mm/s	30		
Infill density/pattern	50%/cubic		
Wall count	2		
Support	**none**		
Test no	**010**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	No discernible difference between 010 and 009. Next steps: lager layer height at this stage is a good idea and see how much that affects the overall finish. Before re-trying supports.	
file	test_v2		
Layer height - Top/Bottom thickness	0.6/2.12		
Temp print/ bed	205/60		

Speed mm/s	**20**		
Infill density/pattern	50%/cubic		
Wall count	2		
Support	none		
Test no	**011**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Not a huge reduction in quality but need for support at the end of the mouth is still required. Next steps: add minimal support to the end of mouth. Increase support block to the start of the cut-out shape. Support settings; Overhand angle 33 Patter: lines Wall line count: 0 Density 20 Interface thickness: 0	
file	test_v2		
Layer height - Top/Bottom thickness	**0.7/2.47**		
Temp print/ bed	205/60		
Speed mm/s	**30**		
Infill density/pattern	50%/cubic		
Wall count	2		
Support	none		
Test no	**012**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Similar quality result except for far more clean up, due to stinging and unsatisfactory support- which for some reason is also partially enclosed despite setting it to 0 wall line count? Next steps: Keep block over side detail and start to cut out. Support settings **Structure: tree** Overhand angle 33	
file	test_v2		
Layer height	0.7/2.47		
Temp print/ bed	205/60		
Speed mm/s	30		
Infill	50%/cubi		

density/pattern	c	Patter: zig zag Wall line count: 1 Density 20 Interface thickness: 1.6	
Wall count	2		
Support; Overhand angle 33 **Patter: lines** **Wall line count: 0** **Density 20** **Interface thickness: 0**			
Test no	**013**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Support doesn't seem to have aided the overhand much there is still drooping, and the support seems to have bonded to the object in other areas, even though it was to the plate only. A lot of stringing may be creating an additionally strong bond between support and body of object, maybe reducing the print temp will help. Also returning to the ideal layer height of 0.6	
file	test_v2		
Layer height - Top/Bottom thickness	0.7/2.47		
Temp print/ bed	205/60		
Speed mm/s	30		
Infill density/pattern	50%/cubic		
Wall count	2		
Support; **Structure: tree** Overhand angle 50 Patter: zig zag Wall line count: 1 Density 20 Interface thickness: 1.6			
Test no	**014**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	I also found that retraction had been enabled so this may also account for the stringing. Reduced temperature worked fine for adhesion but the result	
file	test_v2		
Layer height - Top/Bottom	**0.6/2.12**		

thickness		is exactly the same as test no 010. Next step attempt to add supports again this time with retraction	
Temp print/ bed	**200/60**		
Speed mm/s	20		
Infill density/pattern	50%/zigzag		
Wall count	2		
Support	None		
Test no	**015**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Going to attempt a supported version with previous settings. Support angle set 80° allows for less support overall only affecting the last few layers at the end of the opening. No support over left side detail. Also trying only enabling support interface on the floor to see if it helps with addition to the top layer not being too stiff. Successful print minor drooping but much reduced from previous print. No stringing. Next step, try adding roof interface support as well as allowing some support to the left-hand details. May try adjusting files to make details less pronounced ready for body tests.	
file	test_v2		
Layer height - Top/Bottom thickness	0.6/2.12		
Temp print/ bed	200/60		
Speed mm/s	20		
Infill density/pattern	50%/zigzag		
Wall count	2		
Support; **Overhand angle 80** **Patter: zig zag** **Wall line count: 1** **Density 20** **Interface thickness: 1.6* only enabled support floor**			
Test no	**016**	**ANALYSIS**	**IMAGE**

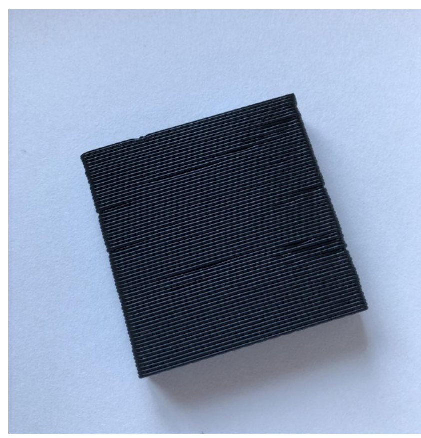
Nozzle	0.8	Removed support blocker from left hand detail. Added roof interface to support. Strangely it made no difference to the quality of the overhang perhaps increasing the overhang angle will help. The small amounts of support in the left-hand detail fused completely and did not increase any detail or overhanging.	
file	test_v2		
Layer height - Top/Bottom thickness	0.6/2.12		
Temp print/ bed	200/60		
Speed mm/s	20		
Infill density/pattern	50%/zigzag		
Wall count	2		
Support; Overhand angle 80 Patter: zig zag Wall line count: 1 Density 20 **Interface thickness: 1.6**			
Test no	**017**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Add support blocker to left hand detail. Decrease Overhang angle to 70° Reduced overhand angle made no difference just slightly more difficult to remove. Going to try printing on the side to see how much better the quality would be printed with this origination	
file	test_v2		
Layer height - Top/Bottom thickness	0.6/2.12		
Temp print/ bed	200/60		
Speed mm/s	20		
Infill density/pattern	50%/zigzag		

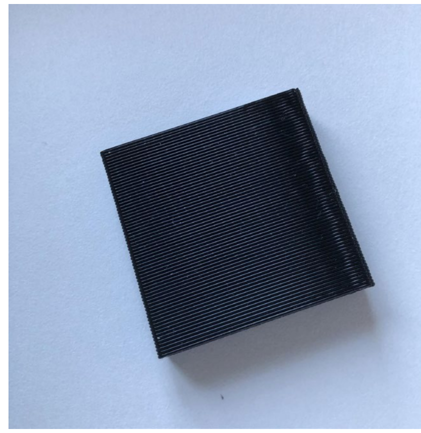
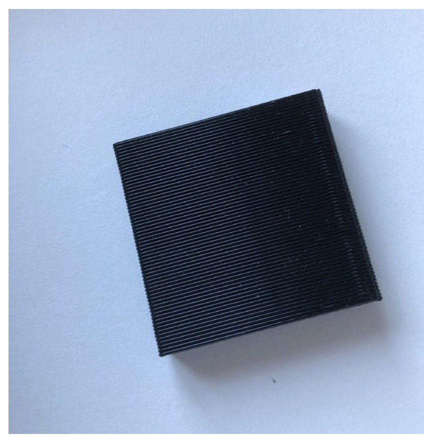
Wall count	2		
Support; **Overhand angle 70** Patter: zig zag Wall line count: 1 Density 20 Interface thickness: 1.6			
Test no	**018**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Remove supports and try printing on the left side to see how much better the print would be if the orientation was changed to suit the print more.	
file	test_v2		
Layer height - Top/Bottom thickness	0.6/2.12		
Temp print/ bed	200/60		
Speed mm/s	20		
Infill density/patt ern	50%/zigz ag		
Wall count	2		
Support	**none**		
Origination	**Side (left)**		
Test no	**019**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	changed sample test, just reduce the depth of the detail to see if I could reduce drooping This worked well significantly reduced drooping but still noticeable depth that should still avoid dry brush when painting	
file	**test_v3**		
Layer height - Top/Bottom thickness	0.6/2.12		
Temp print/ bed	200/60		

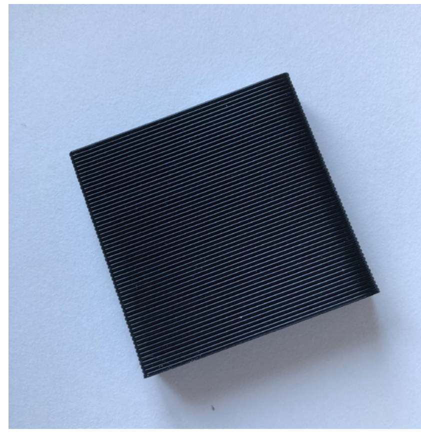
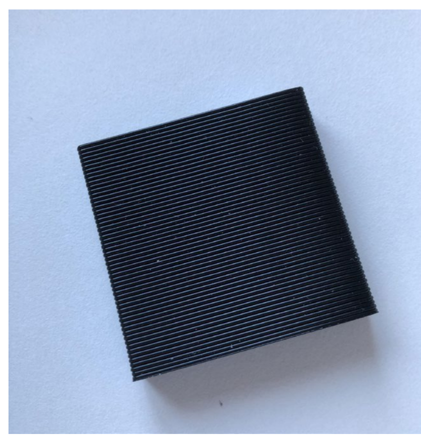
Speed mm/s	20	One final new test sample to try with curved edges on detail to see how the printer responds	
Infill density/pattern	50%/zigzag		
Wall count	2		
Support; **Overhand angle 80** **Patter: zig zag** **Wall line count: 1** **Density 20** **Interface thickness: 1.6**			
Origination	**Up**		
Test no	**020**	**ANALYSIS**	**IMAGE**
Nozzle	0.8	Overall clarity of left-hand detail is not great, it doesn't cause any sagging, but paint would probably pool here not giving great clarity. I think I have learnt everything I can from the initial set up of the 0.8 nozzle for this project so will me moving on to the 1.0mm nozzle and proceeding through tests to ascertain the viability and look of 1.0mm nozzle extrusion.	
file	**test_v4**		
Layer height - Top/Bottom thickness	0.6/2.12		
Temp print/ bed	200/60		
Speed mm/s	20		
Infill density/pattern	50%/zigzag		
Wall count	2		
Support	Overhand angle 80 Patter: zig zag Wall line count: 1 Density 20		

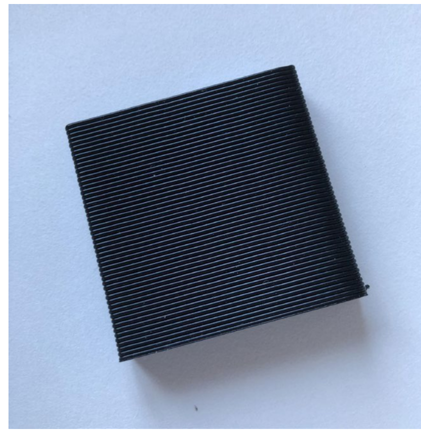
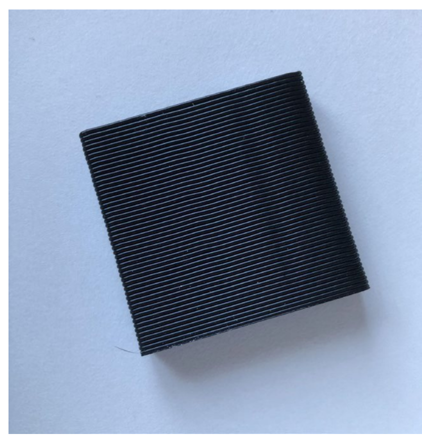
	Interface thickness : 1.6		
Origination	UP		

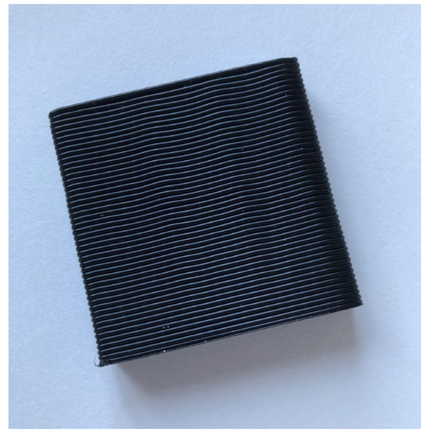
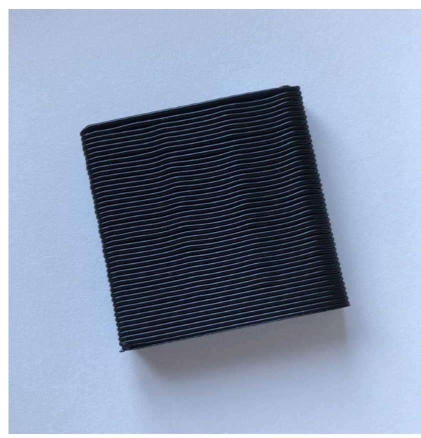
Creality Ender-3 V2 1.0 Nozzle	Generic PLA 1.0 Nozzle
Wall thickness	2.0 mm
Travel Enable retraction	True
Cooling enable Print cooling	True
Fan Speed	100%

Test no	021	ANALYSIS	IMAGE
Nozzle	1.0	The adhesion to the plate is much better. There are few minor faults in the layer lines, perhaps due to lack of adhesion between layers. There isn't a huge visual change between the 0.6 layer height of the 0.8 nozzle and the 0.75 of the 1.0mm nozzle. Which makes sense as it is only 0.05mm difference. After doing some research online about setting for layer height I intend to change some settings to increase finish and hopefully increase the layer height look of the piece. The speed of printing is highly impressive.	
file	test1		
Layer height - Top/Bottom thickness	0.75/2.57		
Top/Bottom Layer	4		
Temp print/ bed	200/60		
Speed mm/s	30		
Infill density/patt ern	50%/cubi c		
Wall count	2		
Test no	**022**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Overall quality better no	

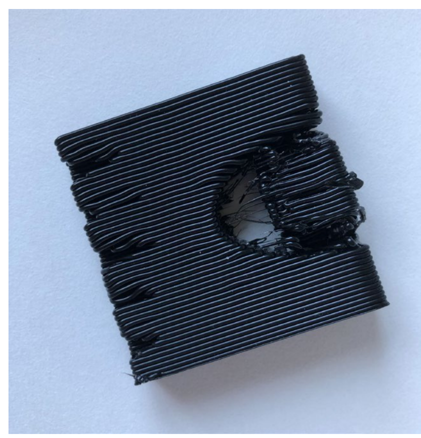
file	test1	anomalies. Going to try pushing the layer height beyond the recommended ¾ top end to 0.8 to see how it handles it.	
Layer height - Top/Bottom thickness	0.75/2.57		
Top/Bottom Layer	**3**		
Temp print/ bed	**230/60**		
Speed mm/s	**25**		
Infill density/pattern	**20% /Zig zag**		
Wall count	2		
Test no	**023**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Still solid and high finish, slightly more noticeably layer lines. Will try increasing this further.	
file	test1		
Layer height - Top/Bottom thickness	**0.8/2.72**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Test no	**024**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Slightly thicker layer lines, still	

file	test1	strong and secure. No flaws. Will try increasing this further.	
Layer height - Top/Bottom thickness	**0.8.5/2.87**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Wall count	20% /Zig zag		
Test no	**025**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Slightly thicker layer lines, still strong and secure. No flaws. Will try increasing this further.	
file	test1		
Layer height - Top/Bottom thickness	**0.9/3.02**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Test no	**026**	**ANALYSIS**	**IMAGE**

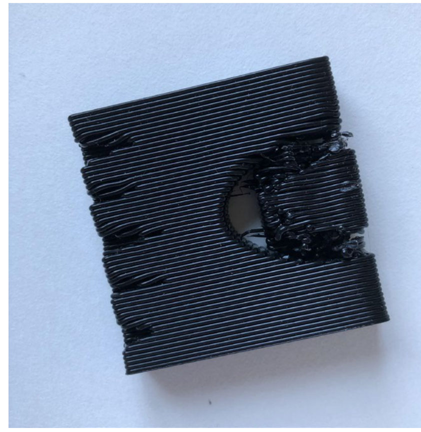
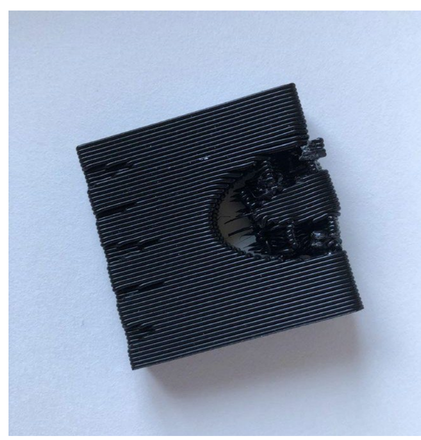
Nozzle	1.0	Slightly thicker layer lines, still strong and secure. No flaws . Will try increasing this further.	
file	test1		
Layer height - Top/Bottom thickness	**0.95/3.17**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Test no	**027**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Slightly thicker layer lines, still strong and secure. A very slight layer wobble . Will try increasing this further.	
file	test1		
Layer height - Top/Bottom thickness	**0.1/3.32**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Test no	**028**	**ANALYSIS**	**IMAGE**

Nozzle	1.0	Slightly thicker layer lines, still strong and secure. Slight layer wobble, some loss of adhesion of final layer, slight wave on side profile. Will try increasing this further.	
file	test1		
Layer height - Top/Bottom thickness	**1.05/3.47**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Test no	**029**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Slightly thicker layer lines, still strong and secure. Slight stronger layer wobble, some loss of adhesion of final layer, slightly more pronounced wave on side profile. Will try one further increase.	
file	test1		
Layer height - Top/Bottom thickness	**1.1/3.62**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		

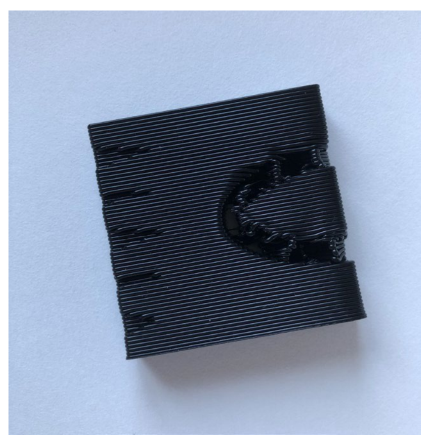
Test no	**030**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Still relatively strong and stable but with some loss of layer control, the final layer is very spaced with some faults throughout print. Will move on to testing test 2 with support.	
file	test1		
Layer height - Top/Bottom thickness	**1.15/3.77**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		

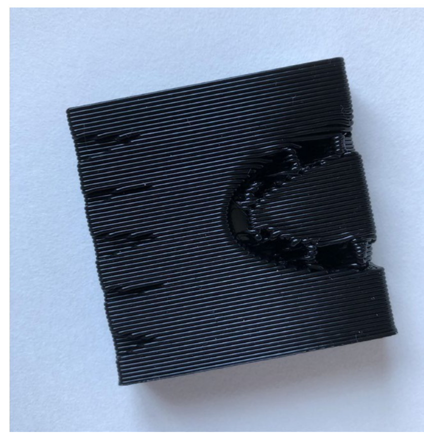
Test no	**031**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Some stringing I think retraction may have been switched off. A Lot of layer adhesion loss both on side detail and overhang. Next steps; try originating upwards.	
file	**test2**		
Layer height - Top/Bottom thickness	**1.0/3.32**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		

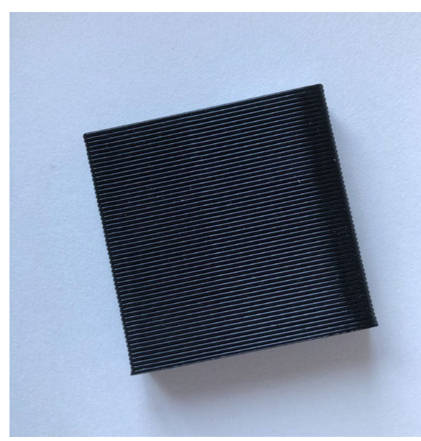
Support; **Overhand angle 70** **Patter: zig zag** **Wall line count: 1** **Density 20** **Interface thickness: 4**			
Orientation	**up**		
Test no	**032**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	A little elephant footing and warping on one side as if shifted, some adhesion issues on back. I think drop down layer height to 0.9 and try original orientation again before moving on to test 3	
file	**test2**		
Layer height - Top/Bottom thickness	**1.0/3.32**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Support	**none**		
Orientation	**Side (left)**		
Test no	**033**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Detail and cut out still to sloppy, Depth is clearly an issue for the detail. Test sample 3 is better for this. As discussed on forums, the increased nozzle size creates stronger layers which also	
file	**test2**		
Layer height -	**0.9/3.02**		

Top/Bottom thickness		increases the strength between file and support. Worth trying to increase interface thickness, to see if keeps similar detail but helps make it easier to remove.	
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Support; **Overhand angle 60** **Patter: zig zag** **Wall line count: 1** **Density 20** **Interface thickness: 4**			
Orientation	**up**		
Test no	**034**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Increased interface thickness made no difference to detail, nor did it make it much easier to remove- removal it was fine as it was. Test 3 yields better results in regard to the detail not being lost when printed upright, however due to the overhang detail loss as you increase the layer height on the overhang. It may be better at this junction to consider printing on the side to create better print quality. This also allows for deeper recess on the detail, but it is hard to know how this may be affected when moving into production where the part will not be a	
file	**test3**		
Layer height - Top/Bottom thickness	0.9/3.02		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/patt	20% /Zig zag		

ern		perfect square. However, as these frames will be on screen for minimal time perhaps perfect quality is not necessary. Will try test 3 with 0.9-layer height on side orientation next.	
Wall count	2		
Support; Overhand angle 60 Patter: zig zag Wall line count: 1 Density 20 **Interface thickness: 6**			
Orientation	**up**		
Test no	**035**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Shallower detail recess may increase likelihood of paint bleeding/flowing in the groves and distort sharp angles between upper layer and lower. However, this could also be fixed with black. The detail of the overhang is far superior at this angle but this may not be the case when the overall shape becomes less symmetric/square. Will perform some final tests trialing the layer heights and orientation for test 3. 0.8 & 0.75 and up/side.	
file	**test3**		
Layer height - Top/Bottom thickness	0.9/3.02		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Support	-		
Orientation	side		
Test no	**036**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Minimal detail and overhand	

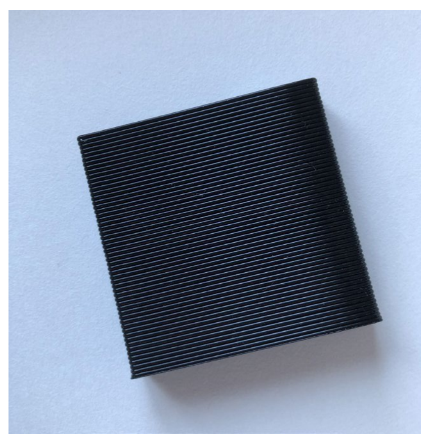
file	**test3**	change in quality, slightly sharper and less stepping. Nest step up right orientation, may also try decreasing overhang angle to 50.	
Layer height - Top/Bottom thickness	**0.8/3.02**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Support	-		
Orientation	side		
Test no	**037**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Minuscule improvement to overhang quality, could be down to reduction in layer height since test 034. Will see if this has further changed in tests 038 with further reduction in layer height to 0.75.	
file	test3		
Layer height - Top/Bottom thickness	**0.8/2.72**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/patt	20% /Zig zag		

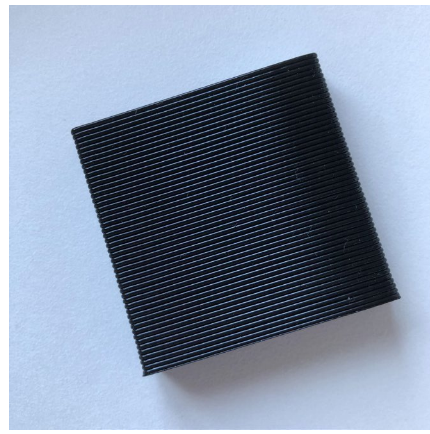
ern			
Wall count	2		
Support; **Overhand angle 50** **Patter: zig zag** **Wall line count: 1** **Density 20** **Interface thickness: 4**			
Orientation	**up**		
Test no	**038**	**ANALYSIS**	**IMAGE**
Nozzle	1.0	Surprisingly the overhang quality was worse at this layer height. But side detail is even neater. 0.75 is the highest recommended layer height at ¾ of the nozzle width.	
file	test3		
Layer height - Top/Bottom thickness	**0.75/2.57**		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Support; Overhand angle 50 Patter: zig zag Wall line count: 1 Density 20 Interface thickness: 4			
Orientation	up		
Test no	**039**	**ANALYSIS**	**IMAGE**

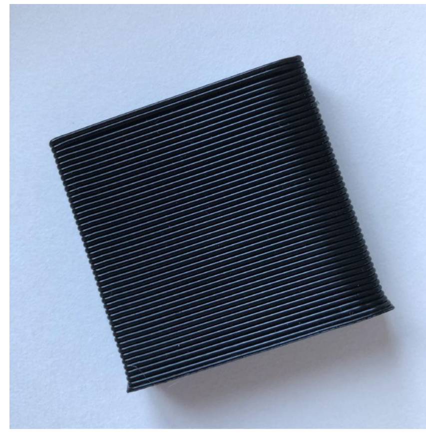
Nozzle	1.0	High definition in cut out and detail. However, begin to lose those stronger layer lines. Will now move on to testing 1.2mm nozzles.	
file	test3		
Layer height - Top/Bottom thickness	0.75/2.57		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		
Infill density/pattern	20% /Zig zag		
Wall count	2		
Support	-		
Orientation	**side**		
Test no	**040**	**ANALYSIS**	**IMAGE**
Nozzle	1.0		
file	test1		
Layer height - Top/Bottom thickness	0.9/3.02		
Top/Bottom Layer	3		
Temp print/ bed	230/60		
Speed mm/s	25		

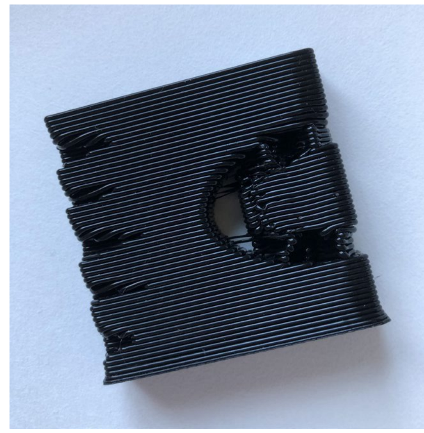
Infill density/pattern	20% /Zig zag		
Wall count	2		
Support	-		
Orientation	-		

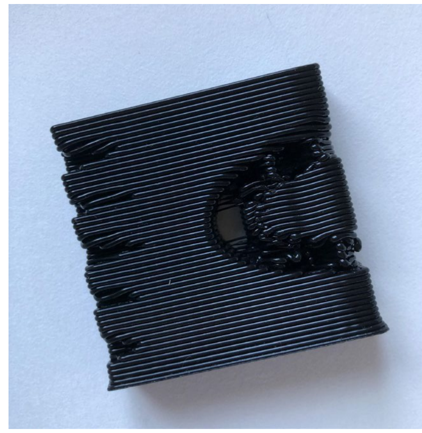
Creality Ender-3 V2 1.2 Nozzle	Generic PLA 1.0 Nozzle
Wall thickness	2.0 mm
Travel Enable retraction	True
Cooling enable Print cooling	True
Fan Speed	100%

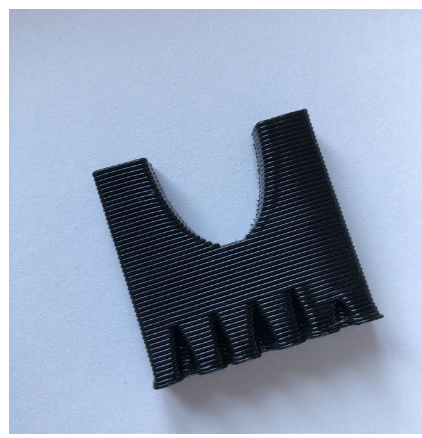
Test no	041	ANALYSIS	IMAGE
Nozzle	**1.2**	Reduced infill as wall thickness is meant to be strong enough to hold. Small amount of infill creating slight deformation to the final surface. Next print no infill required.	
file	**test1**		
Layer height - Top/Bottom thickness	**0.9/3.02**		
Top/Bottom Layer	**3**		
Temp print/ bed	**250/60**		
Speed mm/s	**25**		
Infill density/patter n	**5% / zigzag**		

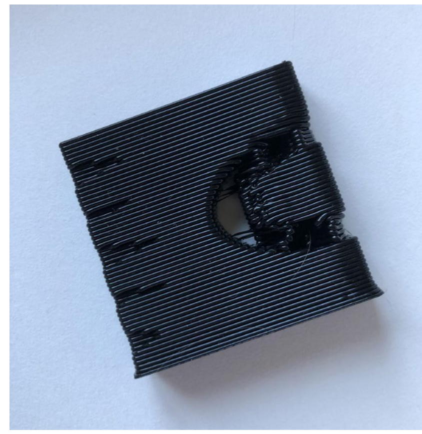
Wall count	**2**		
Support	**-**		
Orientation	**up**		
Test no	**042**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	No infill worked perfectly well, very strong. Noticeable layers increase. Next steps move up 0.1mm.	
file	test1		
Layer height - Top/Bottom thickness	1.0/3.32		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	**-**		
Wall count	2		
Support	-		
Orientation	up		
Test no	**043**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Slight elephant footing on base and slight warping on side, and reduction of addition on top layers.	
file	test1		
Layer height - Top/Bottom	**1.1/3.62**		

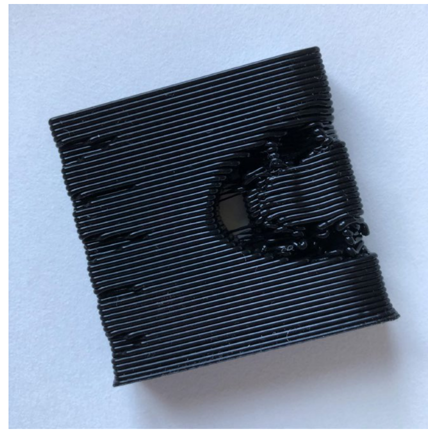
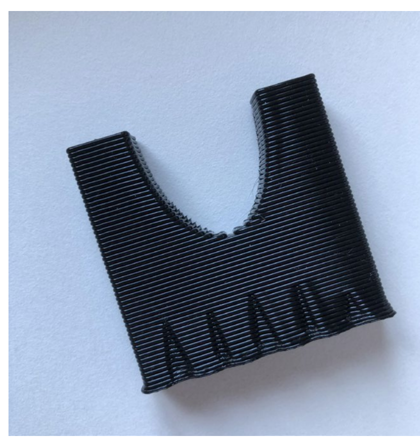
thickness			
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	-		
Wall count	2		
Support	-		
Orientation	up		
Test no	**044**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Large flat elephant foot on base, quite obvious reduction in adhesion throughout print, but predominantly on final 3-5 layers.	
file	test2		
Layer height - Top/Bottom thickness	**1.2/3.92**		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	-		
Wall count	2		

Support	-		
Orientation	up		
Test no	**045**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Slight elephants' foot on base layers- perhaps too hot or not enough cooling, or too fast. Side detail warped and slight detail loss as always on top of cut out on right.	
file	test2		
Layer height - Top/Bottom thickness	**0.9/3.02**		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	**-**		
Wall count	2		
Support; **Overhand angle 60** **Patter: zig zag** **Wall line count: 1** **Density 20** **Interface thickness: 4**			
Orientation	up		
Test no	**046**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Slightly more elephants stepping on base layers- perhaps too hot or not enough cooling, or too fast. Side detail more warped and	
file	test12		
Layer	**0.1/3.32**		

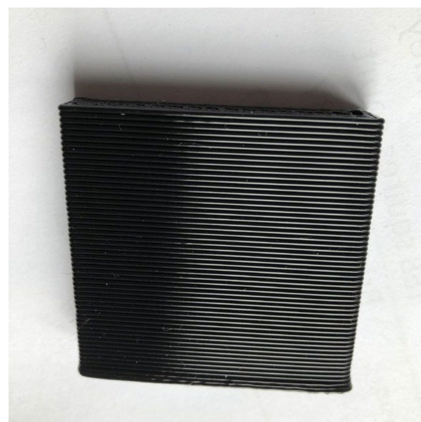
height - Top/Bottom thickness		slightly more detail loss on top of the cut out on right. Increasing layer height reduces the number of layers overall.	
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	-		
Wall count	2		
Support; Overhand angle 60 Patter: zig zag Wall line count: 1 Density 20 Interface thickness: 4			
Orientation	up		
Test no	**047**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Slight elephant footing on base layers, layer layer/nozzle side has created rounded edges to the side detail which is quite nice. The elephant footing is an issue with this orientation as it would likely catch the light, it could be sanded down but if it can be reduced or eradicated in the print itself that would be better. Elephant footing can be caused by the weight of the proceeding elements pushing	
file	test2		
Layer height - Top/Bottom thickness	**0.9/3.02**		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		

Infill density/pattern	**-**	down on the initial layer(s). This could be mitigated by using a chamfer (0.5-0.1)in the design to slightly bevel the first print layer. https://www.youtube.com/watch?v=zlgR3rHg4p8 It can also be reduced in the slicer by using the initial layer horizontal expansion under shell setting in Cura. Take measurement of the body width with foot and without subtract and the half to figure out the amount of reduction needed https://www.youtube.com/watch?v=FH1wUWy7Hjw	
Wall count	2		
Support	**-**		
Orientation	**side**		
Test no	**048**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Continued elephant foot on base but otherwise good render of detail and cut out.	
file	test2		
Layer height - Top/Bottom thickness	**0.1/3.32**		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	**-**		
Wall count	2		

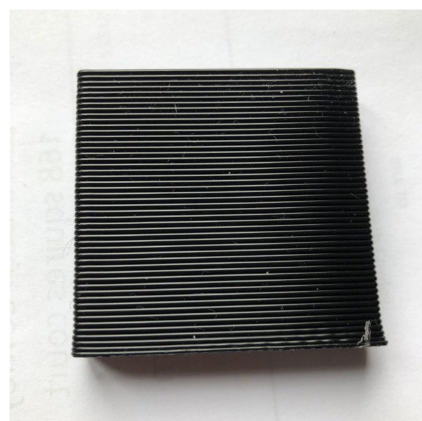
Support	**-**		
Orientation	**side**		
Test no	**049**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Continue elephant foot on first layers, good rendering of side details however very squared of giving a kind of pixel art look, still has some drooping on overhang of cut out shape	
file	test3		
Layer height - Top/Bottom thickness	**0.9/3.02**		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	**-**		
Wall count	2		
Support; **Overhand angle 60** **Patter: zig zag** **Wall line count: 1** **Density 20** **Interface thickness: 4**			
Orientation	**up**		
Test no	**050**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Continue elephant foot on first layers, good rendering of side details second from top cut is actually much longer on this	
file	test3		

Layer height - Top/Bottom thickness	**0.1/3.32**	version, however, remains very squared off giving a kind of pixel art look, still has some more extensive drooping on overhang of cut out shape, support slightly trickier to remove.	
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	**-**		
Wall count	2		
Support; Overhand angle 60 Patter: zig zag Wall line count: 1 Density 20 Interface thickness: 4			
Orientation	up		
Test no	**051**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Quite a pronounced elampnt foot on this test, otherwise detail and cut out are clean and satisfactory.	
file	test3		
Layer height - Top/Bottom thickness	**0.9/3.02**		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		

Infill density/pattern	**-**		
Wall count	2		
Support	**-**		
Orientation	**side**		
Test no	**052**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Quite a pronounced elephant foot on this test also, otherwise detail and cut out are clean and satisfactory. Next Step: action to reduce elephant foot, which can be caused by the weight of the proceeding elements pushing down on the initial layer(s). This could be mitigated by using a chamfer (0.5-0.1) in the design to slight bevel the first print layer. https://www.youtube.com/watch?v=zlgR3rHg4p8 It can also be reduced in the slicer by using the initial layer horizontal expansion under shell setting in Cura. Take measurement of the body width with foot and without subtract and the half to figure out the amount of reduction needed. https://www.youtube.com/watch?v=FH1wUWy7Hjw I will attempt to alter the initial layer horizontal expansion to -0.5 on some tests of 0.2 nozzle at 0.9 and 1.0mm layer heights	
file	test3		
Layer height - Top/Bottom thickness	**0.1/3.32**		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	**-**		
Wall count	2		
Support	**-**		
Orientation	side		

		of test sample 1, 2 and 3. As if I can get the elephant footing under control, printing at a 1.2 nozzle width would speed up printing overall due to being able to print without the need for internal infill and strengthening due to more material being used. I will then print multiples to do paint tests as well as trying an alternative light filament and try applying darker paint and dry brushing/burnishing away.	
Test no	**053**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Some elephant footing remains, good layer addition.	
file	**test1**		
Layer height - Top/Bottom thickness	**0.9/3.02**		
Top/Bottom Layer	3		
initial layer horizontal expansion	**-0.5**		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	-		
Wall count	2		
Support	-		

Orientation	**up**		
Test no	**054**		**IMAGE**
Nozzle	1.2	Elephant footing remains, no change between this and print 047. Slight fault/anomaly found on the front right-hand side of print. Some loops and faults in bottom detail sides.	
file	**test2**		
Layer height - Top/Bottom thickness	0.9/3.02		
initial layer horizontal expansion	-0.5		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	**-**		
Wall count	2		
Support	-		
Orientation	up		
Test no	**055**		**IMAGE**
Nozzle	1.2	Little to no change to elephant foot and overall quality between this and print 051.	
file	**test3**		
Layer height - Top/Bottom thickness	0.9/3.02		

initial layer horizontal expansion	-0.5		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	**-**		
Wall count	2		
Support	-		
Orientation	up		
Test no	**056**	**ANALYSIS**	**IMAGE**
Nozzle	1.2	Some elephant footing remains, good layer addition.	
file	**test1**		
Layer height - Top/Bottom thickness	**1.0/3.32**		
Top/Bottom Layer	3		
initial layer horizontal expansion	**-0.5**		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/patt	-		

ern			
Wall count	2		
Support	-		
Orientation	**up**		
Test no	**057**		**IMAGE**
Nozzle	1.2	No change to elephant foot compared to print 048. Similar fault to right hand profile as with 054, similar fault found in edges to bottom detail.	
file	**test2**		
Layer height - Top/Bottom thickness	1.0/3.32		
initial layer horizontal expansion	-0.5		
Top/Bottom Layer	3		
Temp print/ bed	250/60		
Speed mm/s	25		
Infill density/pattern	**-**		
Wall count	2		
Support	-		
Orientation	up		
Test no	**058**		**IMAGE**

<table>
<tr><td>Nozzle</td><td>1.2</td><td rowspan="11">Similar level of elephant footing as with test 052,

All in all, initial layer horizontal expansion has proven unsuccessful in mitigating the elephant food issue at higher nozzle heights, most likely a better result may be found by altering the actual model by including a bevel on edges you intent to print from, alternatively, cutting and sanding would eliminate this slight issue.

I will now move on to filament and paint tests. As well as designing the overall puppet construction and replacement components.</td><td rowspan="11"></td></tr>
<tr><td>file</td><td>test3</td></tr>
<tr><td>Layer height - Top/Bottom thickness</td><td>1.0/3.32</td></tr>
<tr><td>initial layer horizontal expansion</td><td>-0.5</td></tr>
<tr><td>Top/Bottom Layer</td><td>3</td></tr>
<tr><td>Temp print/ bed</td><td>250/60</td></tr>
<tr><td>Speed mm/s</td><td>25</td></tr>
<tr><td>Infill density/pattern</td><td>-</td></tr>
<tr><td>Wall count</td><td>2</td></tr>
<tr><td>Support</td><td>-</td></tr>
<tr><td>Orientation</td><td>up</td></tr>
</table>

Appendices C.5.1 Crafty Witch Questionnaire – Sam Shaw

Thank you for agreeing to answer some questions about the micro short film Crafty Witch as part of my PhD case study review stage. The questions will be based around your opinion and knowledge as filmmakers/modelmakers/animators and how well you feel the visual and movement was captured within the animated sequence. Please feel free to contact me for any further information or queries you may have about the film or questionnaire. Attached is an information document explaining what and how this information will be used, once you have read this document and completed the survey please fill in and sign the attached consent form, and return to Laura-Beth Cowley at : **[Email removed for security]**

Question 1.

Witches on broomsticks, featured in *The History of Witches and Wizards* (1720) — Source (Wellcome Library)

The aim of the film from a research perspective was to combine two historic art forms, classic wood cuts found at the time of the Witch Trials [see above] and the animated UPA/Cartoon modern style of the 50's, by using 3D printing to create a novel aesthetic style.

How well do you believe these styles were combined and what do you believe the 3D printing brought to the over visual look of the film?

Super successfully. Combining two very different stylistic approaches using a medium that hasn't been used broadly to represent them before is not an easy task, but the limitations and attributes of 3D printing have even been used to celebrate both art styles in this. I love how both styles obviously link to the past but are brought to life using incredibly modern tech - giving the visual style a unique creative life of its own.

Question 2 - In the production of the film a mix of 3D printing technologies were used. The heads and bodies used Fused Deposition Modelling with increased layer heights, this was emphasized further by back paining into the recess, to highlight the layer lines to mimic the line texture found in wood cuts for the period. The hands, eyes, mouths, hats and shoes were created using SLA resin printing which allowed for extremely high detailed prints that needed minimal sanding, before painting with acrylic paint in multiple layers, allowing for multiple replacement parts that had both depth and volume, these process can be seen in the attached Making of video.

Do you think the mix of 3D printing created a unique style profile for the film and do you think it achieved the intended look?

The mix of 3D printing techniques definitely added interest and created an intended visual style. Having the more textured material on fiddlier assets like hands would have muddied the clear visuals on show in the film.

Question 3 - How would you rate the quality of the final film in regard to production and overall final look?

As high as I'm allowed. Think it's a great mix of good production values and handmade charm.

Question 4 -Comparing the original 2D animatic and the final stop-motion film, do you think the use of the replacement stop-motion process has added to the overall look of the film and if so in what way?

I think stop motion makes this film 100% better. 2d digital animation often has a sheen to it and a fast turnaround and an audience can see that. By changing up medium to something an audience sees less of and that obviously requires a longer labor of love, it adds a whole other level of interest. Stop motion also suits the tone of the film, as it's often the go to animation style for more macabre animations.

Question 5 - What do you feel could be improved with the process or look of the piece if further episodes were to be developed?

Maybe tone down the shadows created by the characters a touch, but even they add a DIY charm to everything and help your eye focus on the characters.

Question 6 - Do you have any further feedback regarding the look, animation, narrative or any other aspect of the piece?

Nope. Lovely little film!

Appendices C.5.2 Crafty Witch Questionnaire – Tim Allen

Question 1 - The aim of the film from a research perspective was to combine two historic art forms, classic wood cuts found at the time of the Witch Trials [see above] and the animated UPA/Cartoon modern style of the 50's, by using 3D printing to create a novel aesthetic style.

How well do you believe these styles were combined and what do you believe the 3D printing brought to the over visual look of the film?

I feel the 50's style of animation was very well achieved both in look & bold pose to pose style of animation. Using 3D printing to achieve the wood grain is a commendable idea & a nice use of the 'grainy' result it gives you. I feel that to reflect wood carvings, as shown in the illustration above, I would have gone even further with a more distinct carved look of having the wood grains further apart. The wood grain effect is a subtle nice touch currently.

Question 2 - In the production of the film a mix of 3D printing technologies were used. The heads and bodies used Fused Deposition Modelling with increased layer heights, this was emphasized further by back paining into the recess, to highlight the layer lines to mimic the line texture found in wood cuts for the period. The hands, eyes, mouths, hats and shoes were created using SLA resin printing which allowed for extremely high detailed prints that needed minimal sanding, before painting with acrylic paint in multiple layers, allowing for multiple replacement parts that had both depth and volume, these process can be seen in the attached Making of video.

Do you think the mix of 3D printing created a unique style profile for the film and do you think it achieved the intended look?

I feel that this is a well thought out use of different approaches to 3D printing & combining the techniques. The animation movements & character designs are so distinctive that it makes the wood grain a subtle effect rather than a key feature. As an extreme example, the Weetabix commercial on the Mary Celeste has a much bolder wood effect. Perhaps this is too extreme for your intentions, but something in between that & your 3D print effect with back painting would make it more prominent. I do like the mix of grainy areas & smooth surface areas as part of the 50's cartoony look. The cartoons of the 50s that you are emulating did indeed have a bold simplicity to them which the smooth areas reflect well. I also appreciate the bold outlines you give the characters in keeping with the 50s style.

Question 3 - How would you rate the quality of the final film in regard to production and overall final look?

You’ve been very clear in the style of presentation you want to achieve & wholeheartedly embraced it. The use of emulating a film projection & silent movie titles with flickery lighting & shakey image all help to recreate the look of those times. Equally well added to by the hiss of audio starting up, as if an old recording of a pianist adding their score to a live audience. A nice touch in the old school audio beep at the end when the film reel runs to it’s finish.

Question 4 - Comparing the original 2D animatic and the final stop-motion film, do you think the use of the replacement stop-motion process has added to the overall look of the film and if so in what way?

The 2D animatic is very successful in being used to plan out all the replacement parts to be made. In fact it works so well in the 2D style that it opens the question of whether a stop motion or 2D version could be better. The stop motion version gives a mildly less smooth final quality of animation compared to the animatic. It’s only a subtle difference & it’s possible to argue that very slightly jerkier animation adds to the feel of an old film print that is worn & rough around the edges. Of course the desire for characters carved from wood using the wood grain effect provided by 3D printing completely favours a stop motion look.

2D also leans itself to clear black outlines. Most of this is replicated on the stop motion replacement parts well so isn’t lost.

Question 5 - What do you feel could be improved with the process or look of the piece if further episodes were to be developed?

I suggest making the wood grain effect even bolder & clearer as it’s currently subtle & can get lost in the cut & thrust of dynamic animation & character moments. There could even be an obvious argument to carve the replacement faces out of real wood! However from a production standpoint, the current approach is efficient for making future episodes that would hope to use duplicates of the same parts, especially if additional animators & setups would be required.

The 2D ‘test run’ was a fantastic way to explore the look, feel & parts needed for a pilot. With time & familiarisation of the process, less detail may be needed in this planning stage.

Question 6 - Do you have any further feedback regarding the look, animation, narrative or any other aspect of the piece?

The animation timing is fantastic & the snappy feel is both entertaining & a brilliant use of replacement parts. The narrative is short, fun & quick to accomplish its goal. Much of the film is used up by the text to set up the scenario. This doesn't seem to drag but it is worth pondering other ways to balance the need to literally tell the audience what they are about to watch, instead of taking them on the ride visually.

The look & feel is instantly appealing & grabs the audience's attention then goes forward to raise smiles & leave you satisfied. It is a very enjoyable watch! If anything, the audience will not appreciate all the work that has gone into the process & the labour taken to create the replacement parts. I'm very glad that you've made the 'Making of' to accompany it & allow your effort to shine!

Appendices C.5.3 Crafty Witch Questionnaire – Luis Cook

Question 1 - The aim of the film from a research perspective was to combine two historic art forms, classic wood cuts found at the time of the Witch Trials [see above] and the animated UPA/Cartoon modern style of the 50's, by using 3D printing to create a novel aesthetic style.

How well do you believe these styles were combined and what do you believe the 3D printing brought to the over visual look of the film?

I think the 3D printing could possibly have been produced by hand – but as a streamlined professional pipeline in animation it makes sense to test in CG – then 3d print. This allows for change, adaption, flexibility to try out different things with the animation. It also allows the same model to be shifted, changed (if rigged) then 3d printed. The final result, well, I'm not sure you would know that the artwork had been 3d printed – it looked hand made. Which is exactly what you want 'aesthetically" from this process. You don't want to go and see a stop motion film and think its been made by robots – it would lose its charm. It's ironic – using such high tech stuff to produce something so hand crafted. For me, the silent cinema look worked well, the UPA sensibility was extremely clear, the woodcut aesthetic got a little lost – a tad subtle perhaps or maybe the linework was too regular? – but it certainly didn't detract from the enjoyment of watching the film.

Question 2 - In the production of the film a mix of 3D printing technologies were used. The heads and bodies used Fused Deposition Modelling with increased layer heights, this was emphasized further by back paining into the recess, to highlight the layer lines to mimic the line texture found in wood cuts for the period. The hands, eyes, mouths, hats and shoes were created using SLA resin printing which allowed for extremely high detailed prints that needed minimal sanding, before painting with acrylic paint in multiple layers, allowing for multiple replacement parts that had both depth and volume, these process can be seen in the attached Making of video.

Do you think the mix of 3D printing created a unique style profile for the film and do you think it achieved the intended look?

See above.

Question 3 - How would you rate the quality of the final film in regard to production and overall final look?

It looks great. A very professional finish. I have worked in this two and a half D way before at Aardman – although not using 3d printing. 1. I would have loved to have tried this technique 2. I can't tell the difference – you'd never have known computers were involved – which is great, it's what you want. The final look and finish of the film is up there with any work I ever produced in this way, probably better.

Question 4 - Comparing the original 2D animatic and the final stop-motion film, do you think the use of the replacement stop-motion process has added to the overall look of the film and if so in what way?

It has a completely different sensibility. One is flat, unreal, an illustration – a cartoon. The other has presence, physicality, volume, depth – its own sense of reality. Real objects, real paint, real highlights, texture, shadows – real hands articulating. Yet creating something totally artificial and imagined. The paradox of stop motion – then you add 3d printing to the mix – quite a mash up. Would Starevich have approved? Probably yes, they were all inventors excited by new technology.

Question 5 - What do you feel could be improved with the process or look of the piece if further episodes were to be developed?

Story, character, premise aside… Possibly, more depth in the b/g and f/g – rext the runt style? If the woodcut look is important – then accentuate. This puzzle part feel could work well for a series – having all the pieces, pre made. Probably need to be in colour – modern young audiences and all that.

Question 6 - Do you have any further feedback regarding the look, animation, narrative or any other aspect of the piece?

Its beautifully animated – a fabulous collision of old and new.
Narratively – as a series – the process would probably work – in a similar way to some digital 2d replacement processes – but this pushes it further into more interesting territory.
Great job – want to see what series you come up with now.

Appendices C.5.4 Crafty Witch Questionnaire – Adam Taylor

Question 1- The aim of the film from a research perspective was to combine two historic art forms, classic wood cuts found at the time of the Witch Trials [see above] and the animated UPA/Cartoon modern style of the 50's, by using 3D printing to create a novel aesthetic style.

How well do you believe these styles were combined and what do you believe the 3D printing brought to the over visual look of the film?

> The design of the characters and animation style were classcily UPA and were quite successful. The "wood cut" aspect didn't come through as strongly and I only really see it after reading about your intention. Perhaps if the print lines were less fine and had more black in the valleys it would come across more clearly.

Question 2 - In the production of the film a mix of 3D printing technologies were used. The heads and bodies used Fused Deposition Modelling with increased layer heights, this was emphasized further by back paining into the recess, to highlight the layer lines to mimic the line texture found in wood cuts for the period. The hands, eyes, mouths, hats and shoes were created using SLA resin printing which allowed for extremely high detailed prints that needed minimal sanding, before painting with acrylic paint in multiple layers, allowing for multiple replacement parts that had both depth and volume, these process can be seen in the attached Making of video.

Do you think the mix of 3D printing created a unique style profile for the film and do you think it achieved the intended look?

> The mix is great! You can definitely feel the different textures which makes it even more interesting to watch.

Question 3 - How would you rate the quality of the final film in regard to production and overall final look?

> This is a very successful film. It is clear, funny, and charming. The role reversal is very timely. I would love to see more shorts in this style.

Question 4 - Comparing the original 2D animatic and the final stop-motion film, do you think the use of the replacement stop-motion process has added to the overall look of the film and if so in what way?

While the animatic is fun, the final animation is definitely more interesting. Adding limited dimension to a traditional aesthetic feels like a great way to breathe life back into the style. Real texture and real light bring something that could not be achieved in a computer generated equivelant.

Question 5 - What do you feel could be improved with the process or look of the piece if further episodes were to be developed?

I would like to see more dimension and texture in the environmental design. Similarly, in the fx animation (the puff of smoke, and magical symbols) it would be nice to see something unique to this technique as the cloud is relatively flat and the symbols lack a unique texture.

Question 6 - Do you have any further feedback regarding the look, animation, narrative or any other aspect of the piece?

Reading title screens is fun for a short time, but that section didn't pull me as much as the rest of the film. I would like to hear it narrated even in a similar style to the way the witch speaks a form of giberish in the film. Maybe having less to read up front would be an option. I would also like to see something animated and appealing before the title cards come in.

Appendices D.1 List of Interviews Conducted for study

Interviewee – Role	**Date**
Chris Finnegan – Studio Owner/ Animator/ Model Maker	26/03/2018
Andy Gent – Studio Owner / Model Maker	11/01/2019
Jim Parkyn – Model Maker	02/09/2019
Johnny Kelly – Director	19/02/2019
Merlin Crossingham – Director/ Animator	02/04/2020
Brian McLean – Head of RP	06/04/2020
Justin Ranch – Animator	21/06/2020

Appendices D. 2 Copy of Participant Information Sheet

Thank you for agreeing to take part in the research project: **Printing articulated figures: Constructing flexible and extendable figures using mixed material 3D printing for use in stop frame animation.**

This research is being conducted with funding from the UK Arts and Humanities Research Council as part of a PhD based at the University of the West of England, Bristol. The researcher is looking at the use of 3D printing and other digital fabrication techniques within the Animation industry, specifically the Stop-motion animation pipeline. The research is looking primarily at the ways in which 3D printing may be better utilised within the animation pipeline as well as documenting the ways in which it has already impacted the industry, style and development of stop-motion productions. There will also be research contextualizing the history of the stop-motion process and the impact of new technologies.

By agreeing to participate in this study you are helping to aid new design and processes into the animation industry, your wealth of knowledge, skills and experience may help the researcher to understand what needs and requirements are needed to greater help create a new or better-working dynamic between animators, model makers filmmaker and technology. hopefully creating new types of puppets or adapting modern techniques to better or add to the animation process.

By completing the consent form you are giving your permission for any information discussed or provided during email or recorded interviews for use in their research. In accordance with ethics you are able to remove yourself and your information from the study up to 1 month after the interview date. Below is some further information about redaction and the different ways the research could be disseminated.

Redaction

You are able to request a copy of the transcript of the interview, if you require or wish to redact information from the conversation on reviewing the transcript please indicate this by highlighting the information you wish to not be included and the type of dissemination you wish to retract form i.e. paper/articles & presentations

Forms of dissemination

Below find an outline of what type of documents and information dissemination methods your information may be used in;

- **Thesis-** The final thesis will be reviewed by my internal supervisors and an examination board before being printed and made publically available electronically via the internet through the UWE online research repository. It may then be requested by other external researchers. (However the thesis can be presented in two ways; a public copy with section redacted i.e. information on a commercially sensitive nature. And a copy for examiners who will read the redacted section for the purpose of examination only).

- **Paper /Posters-** the researcher may be required or selected to write reports, articles or papers for peer reviewed publication such as journals or in conference in the form of an academic poster.

- **Presentations -** The researcher may use the research findings in presentations to other students, academics, students and other audiences in symposia, lectures and talks.

What form will the interview take?

I will conduct the interview and record the audio or visual if applicable. The interviews will take the form of a discussion around the key questions of the study, with plenty of scope to expound on a wide range of issues as they arise. Following the interview, we will ask you to sign a consent form.

What will happen to the data?

The audio and video recordings of interviews will be stored digitally on the University computer system that is protected by password and firewall along with interview transcripts. Direct, fully cited quotations from the interview will be used in the publications that arise from this project.

What if I have concerns after the interview has been conducted?

You are free to withdraw from the project, and withdraw data collected, up to one month after the interview date. Should you choose to do this, data will either be destroyed, or returned to you, as per your wishes.

Contact

If you have any questions or would like to follow up with me after our conversation, feel free to email me, **Laura-Beth Cowley: [researchers email address was supplied]**
Profile:www.uwe.ac.uk/sca/research/cfpr/staff/Laura%20Beth/laura_beth_cowley.html

If you have concerns about the way the study is being conducted, please contact my supervisor at UWE, Centre for Fine Print Research:

Dave Huson
Senior Research Fellow
[supervisors email address was supplied]

Appendices D.3 Copy of Participant Consent Form

Printing articulated figures: Constructing flexible and extendable figures using mixed material 3D printing for use in stop frame animation.

Name		Company/ studio	
Address		Email	
Interviewer			
Date			

Thank you for agreeing to take part in this conversation. Your contribution is very much appreciated. Please read and complete the below form. Please note that you may withdraw your consent up to 1 month after the interview date. To do so please contact UWE researcher Laura-Beth Cowley via email. If working for/within a studio or company setting please ensure all legal and IP information has been cleared and signed by a supervisor/manager or the head of the organisation and thus has received the necessary clearance from your company/studio.

I give permission for my responses to be:

☐Yes ☐No Audio/video recorded by the researcher
☐Yes ☐No Used in academic presentations by the researcher
☐Yes ☐No Used in publications (online and print) by the researcher
☐Yes ☐No Used with my name, and company/studio name*

Do you require to see a copy of the transcribed notes either to redact information or for own records? [*Please refer to the information sheet for advice on redaction/dissemination]

☐Yes ☐No

I... declare to the best of knowledge, that all information and data included in the attached documentation and/or associated with this form is accurate. I have discussed with my company **(if applicable)** and we agree that the information can be disseminated in the ways indicated above.

Appendices D.4 Copy of Image Permission Request Form

Permission Request

[Date]
Name:
Email address:
Dear

Final Research Thesis
****
May I please have your permission to include the material specified below? **Copies are attached**.

****
I request permission to reprint the specified material in this (presentation/publication etc) and in any future academic work such as final thesis that may arise from this initial publication. If you do not control these rights in their entirety, please let me know where else to write. Proper acknowledgement of title, author, publisher and copyright date (for journals: author, article title, journal name, volume, first page of article, and year) will be given. If the permission of the author is also required, please supply a current address. For your convenience, you may simply sign the release form below.

Thank you.

My return address is: **[REMOVED FOR SECURITY]**
Author: Laura-Beth Cowley

Date:

Permission Granted:

Signature(s) Date.